Bombardier Contribution to the 3rd AIAA High-Lift Workshop

Marc Langlois

Hong Yang Kurt Sermeus

Advanced Aerodynamics
Bombardier

AIAA SciTech 2018 Forum
Applied Aerodynamics
Orlando, Florida
January 10, 2018

Overview

- Objectives
- Test Cases
- Flow solver Dragon
- Grids
- Results on JAXA JSM configuration
  - Convergence
  - Impact of curvature correction in turbulence model
  - Impact of laminar-turbulent transition
  - Nacelle installation
- Conclusions

Objectives

- Assess the performance of our high-lift CFD prediction tools:
  - Pointwise for unstructured mesh generation
  - Dragon for flow solution
- Compare results obtained on different grids, in-house generated and supplied by the Workshop committee
- Evaluate impact of turbulence and transition modelling on solution accuracy
- Compare our prediction capabilities to what is assumed to be the best in industry/academia

Test Cases

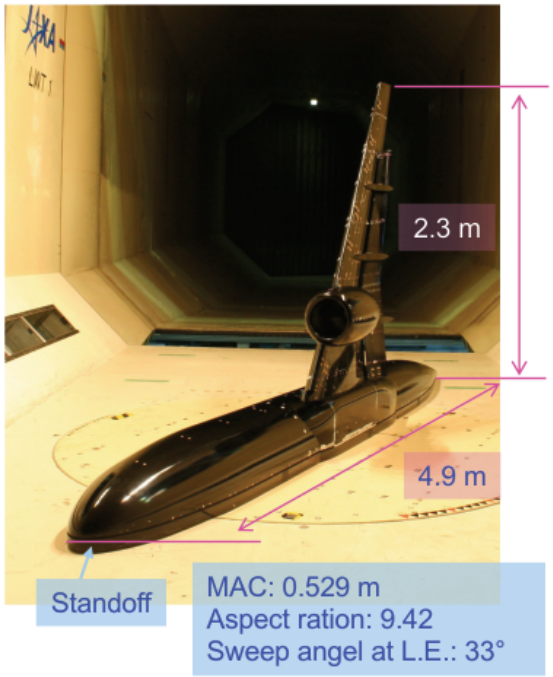
3 test cases / 5 geometries were to be analyzed:

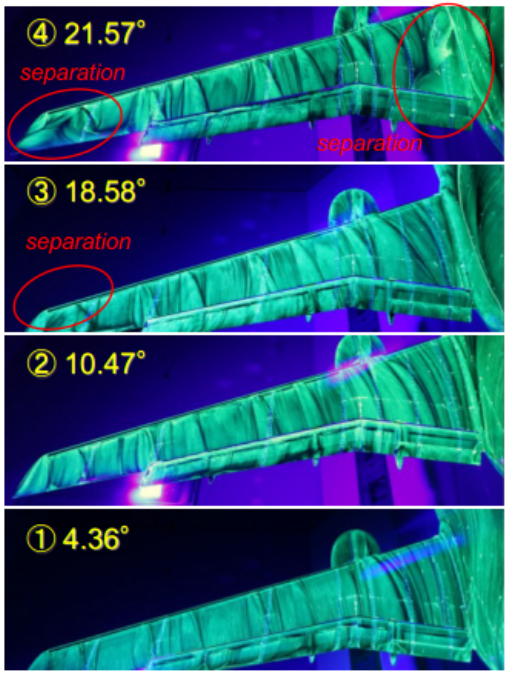
- Cases 1a/c: NASA High-lift Common Model (HL-CRM)
  - Simple WB landing configuration w/o slat tracks or FTFs
  - Full-span slats with slat cuts
  - 2-segment (IB/OB) flaps
  - Case 1a: gapped flaps (between IB/OB and fuselage/IB)
  - Case 2a: partially-sealed flaps
- Cases 2a/c: JAXA High-lift Standard Model (JSM)
  - More complex WB/WBN landing configuration with slat tracks and FTFs
  - Full-span slats with slat cuts
  - 2-segment (IB/OB) flaps, sealed
  - Case 2a: WB
  - Case 2c: WBN (underwing nacelle)
  - Wind-tunnel data available
- Case 3: 2D validation/verification study

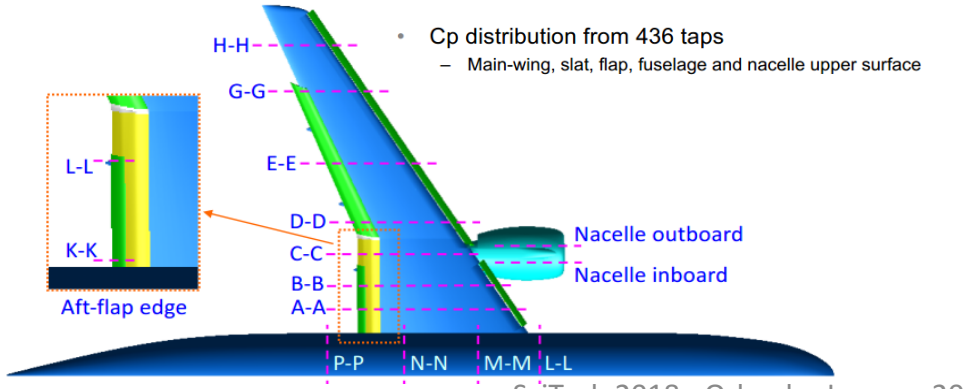
- Many participants submitted data for only some of these cases
- Bombardier submitted data for all cases, on multiple grids

Cases 2a/c – JSM WB & WBN – WT overview

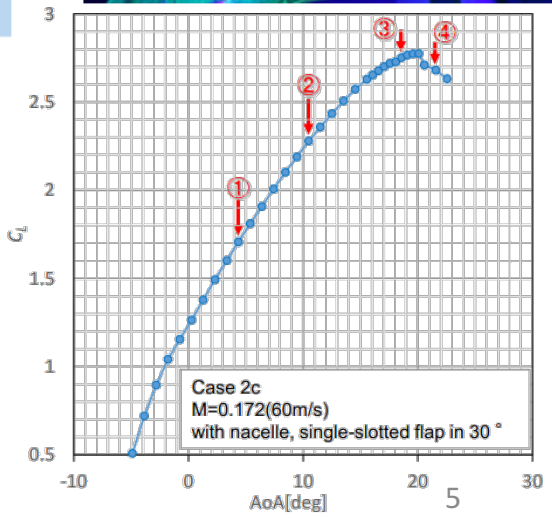
- **JSM Jaxa highlift configuration Standard Model**
  - Tested in 2005 ~ 2009
- **Model specification**
  - 17% of assumed aircraft (100 PAX)
  - 90% span slat
  - Inboard single- or double-slotted flap
  - Outboard single-slotted flap
  - Cylindrical fuselage
  - Pylon-mounted nacelle
  - FTFs
  - No trip dot
- **Test facility**
  - 6.5m by 5.5m JAXA low-speed wind tunnel (JAXA-LWT1)
    - Closed-circuit, atmospheric pressure
  - Estimated* tunnel turbulence intensity was Tu = 0.16 percent (via 2003 JAXA study)







- Cp distribution from 436 taps
  - Main-wing, slat, flap, fuselage and nacelle upper surface

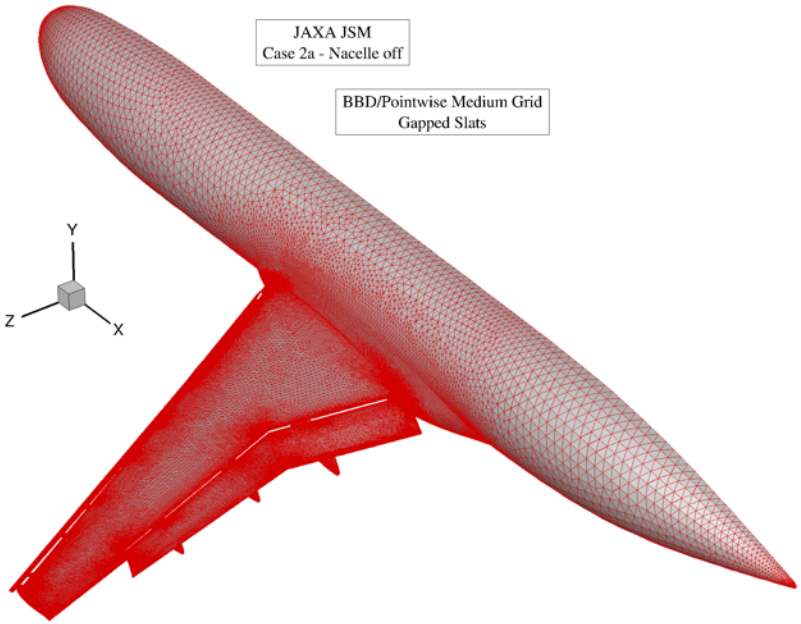


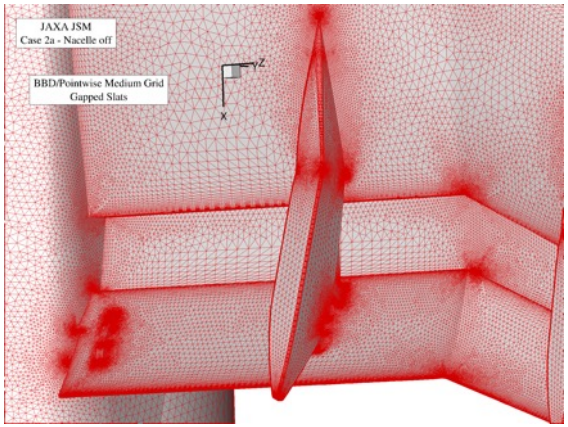
Dragon Flow Solver

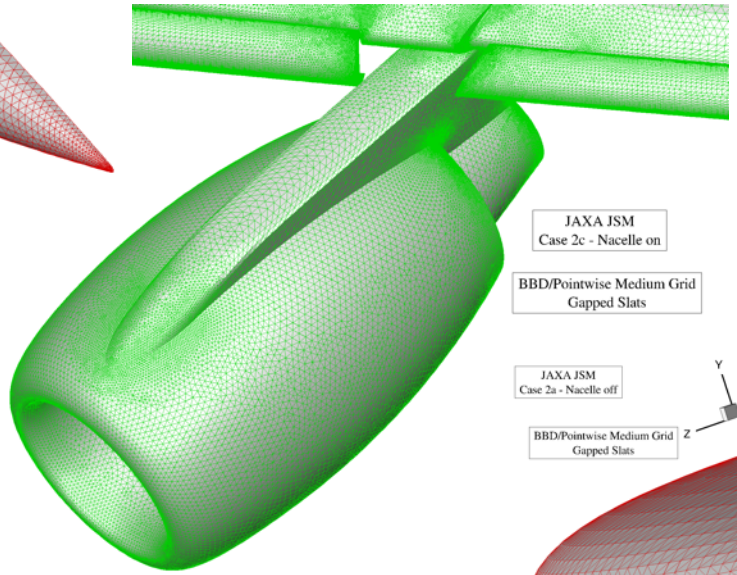
- Bombardier in-house 3D unstructured RANS solver
  - Cell-centered, coupled solver
- Implicit time integration with LU-SGS approach
  - 1st-order accurate in time for steady simulations
- 2nd-order accurate Roe's upwind scheme for convective flux and central differencing scheme for viscous flux discretization
- Turbulence modelling:
  - Standard Spalart-Allmaras
  - **Wilcox k-ω 1988** and 1998
  - SST
  - Bardina-type streamline curvature correction
  - Fully-turbulent or imposed transition location
- Parallel large-scale simulation capability with non-blocking MPI
- Interfaced with CGNS data produced by main-stream commercial grid generators

- Ref.: Yang, H. and Langlois, M. "Towards Accurate Simulation of Aircraft High-Lift Flows with One- and Two-Equations Turbulence Models", 62nd CASI Aeronautics Conference, May 2015.

JAXA JSM – Cases 2a/2c – Bombardier grids

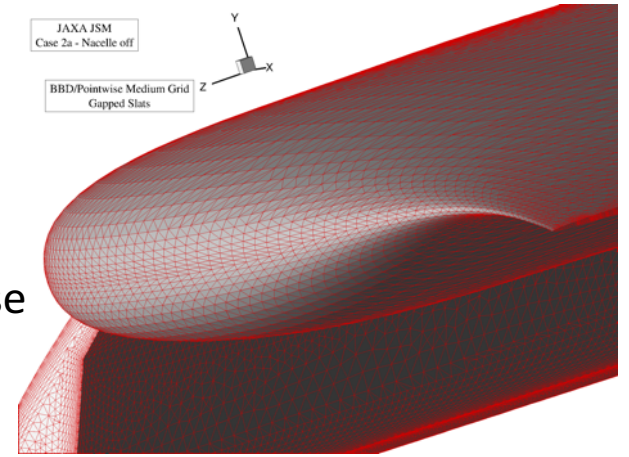




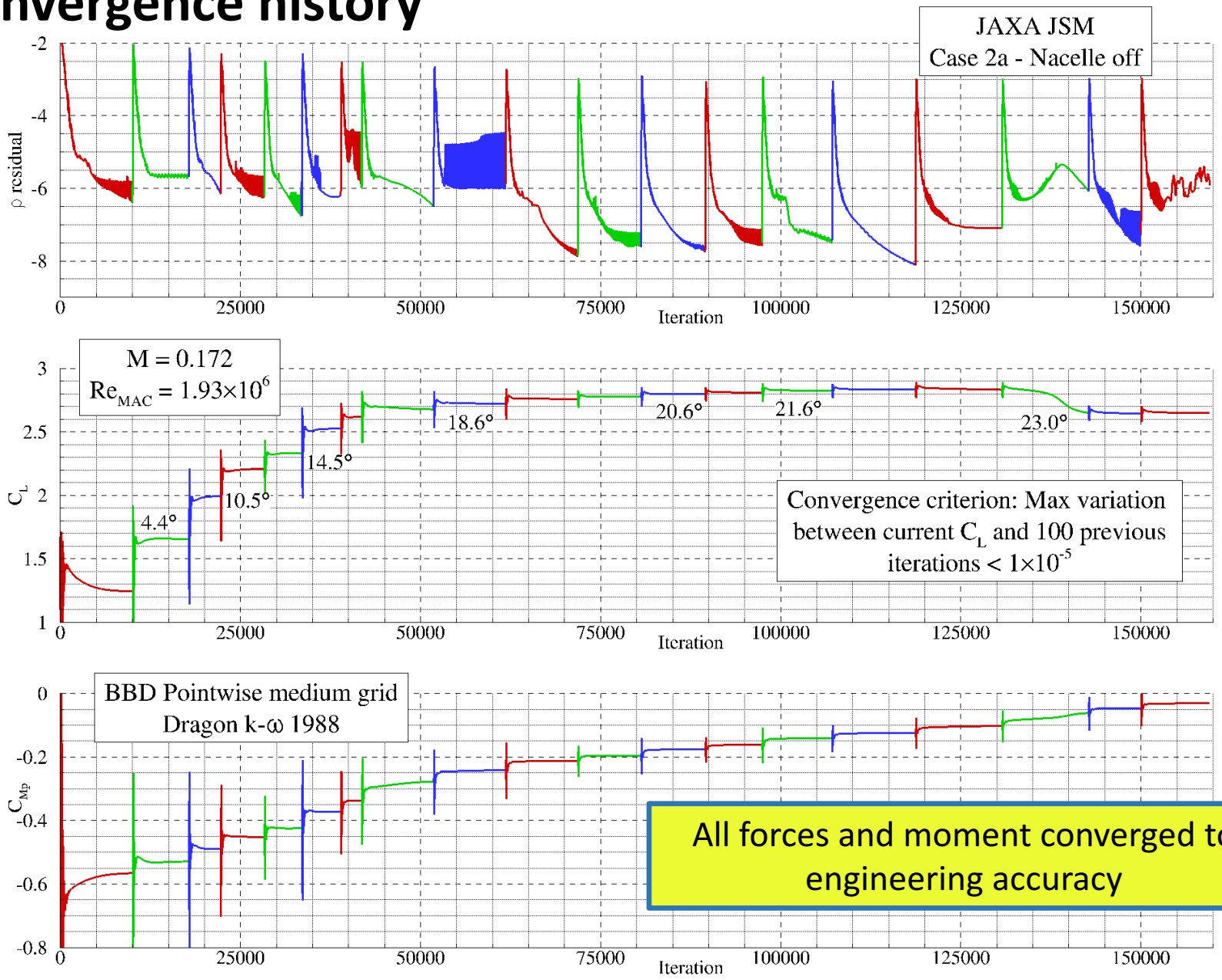


	Case 2a	Case 2c
Nodes	17 708 448	21 720 656
Cells	41 695 790	50 488 218
Fuselage	35 826	35 826
Wing	224 280	233 538
Slats	289 914	247 623
Flaps	253 048	253 048
Nacelle	-	174 472

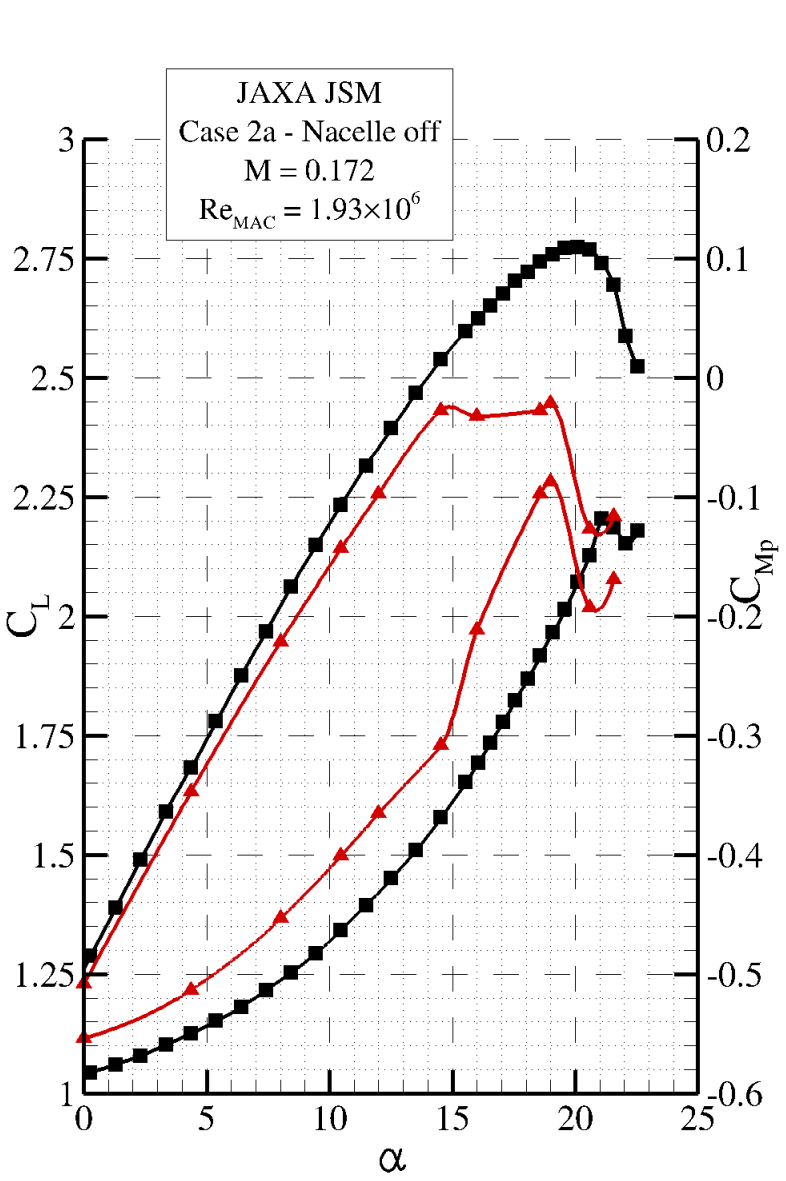
Generated with Pointwise
Medium grid guidelines

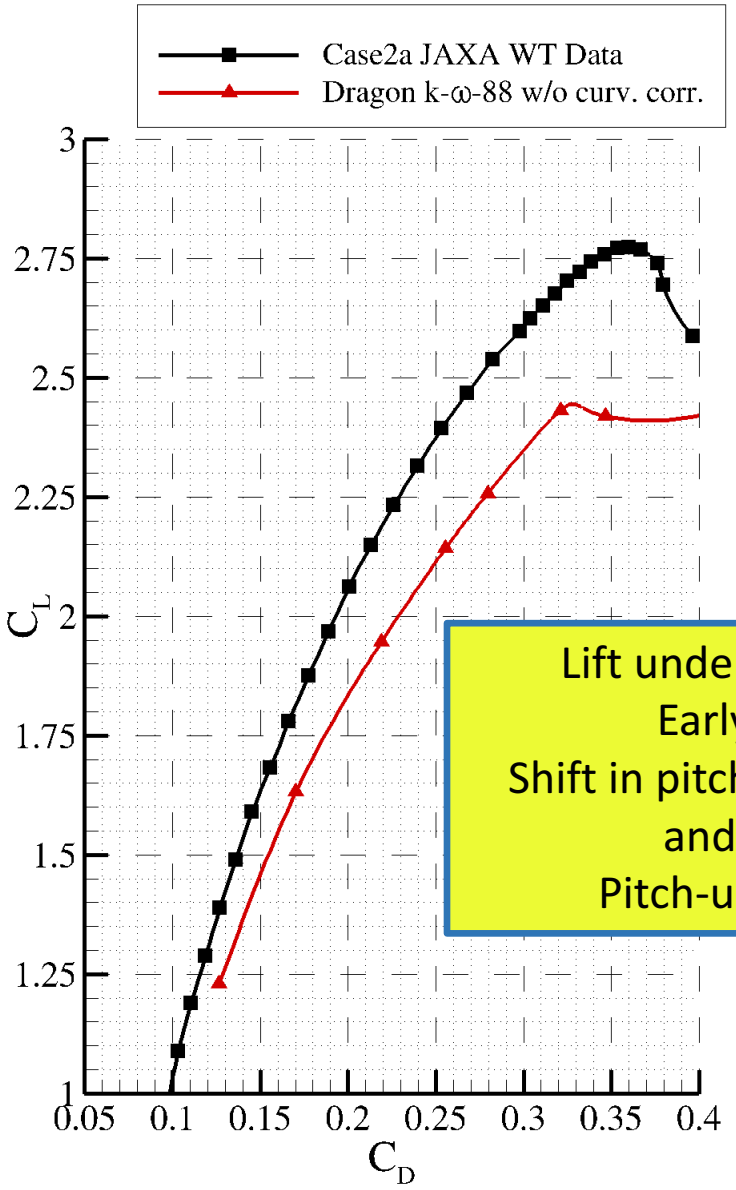


Convergence history



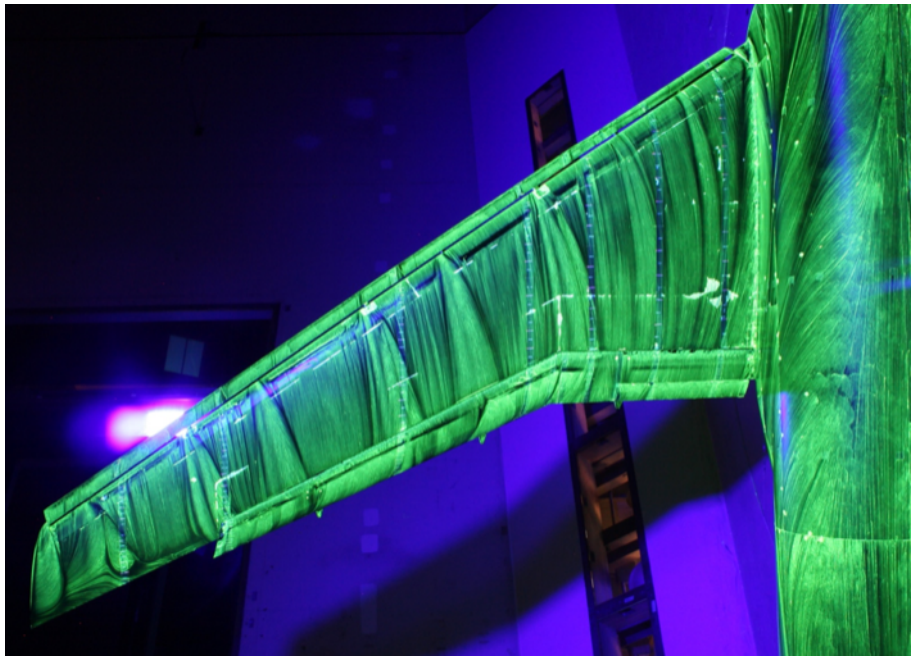
Early results: forces & moments

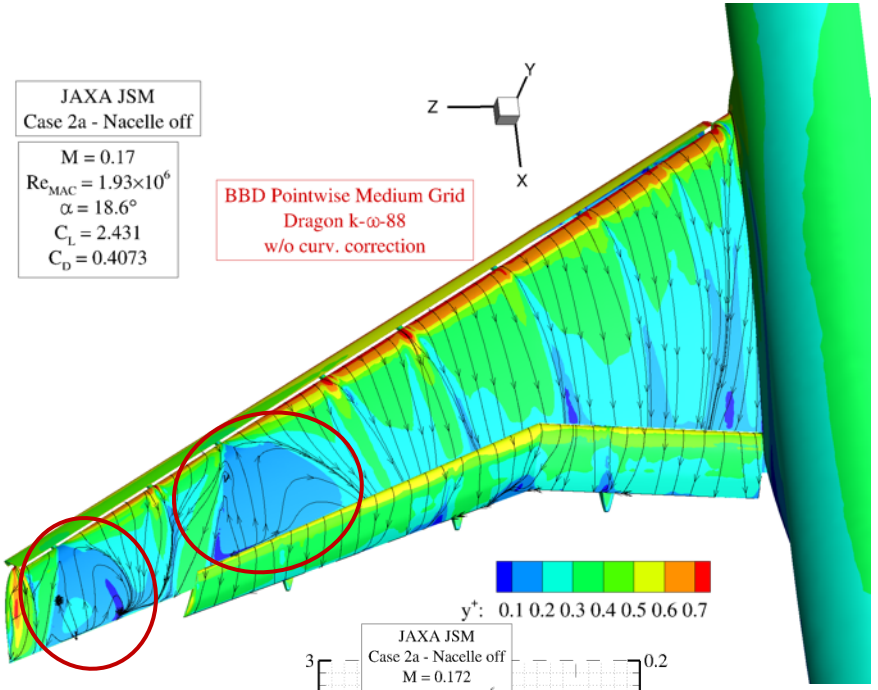


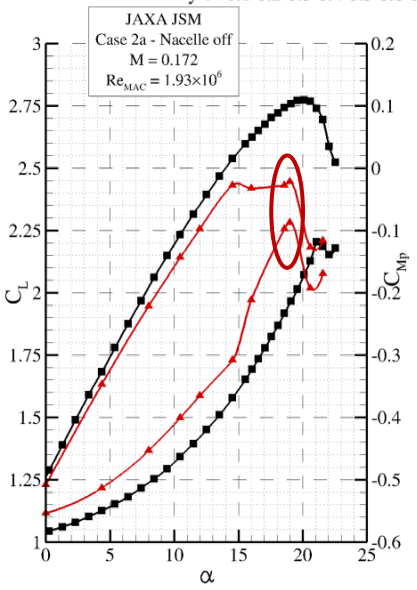


Lift underpredicted
Early stall
Shift in pitching moment and drag
Pitch-up at stall

Early results: surface flow pattern at α = 18.6°

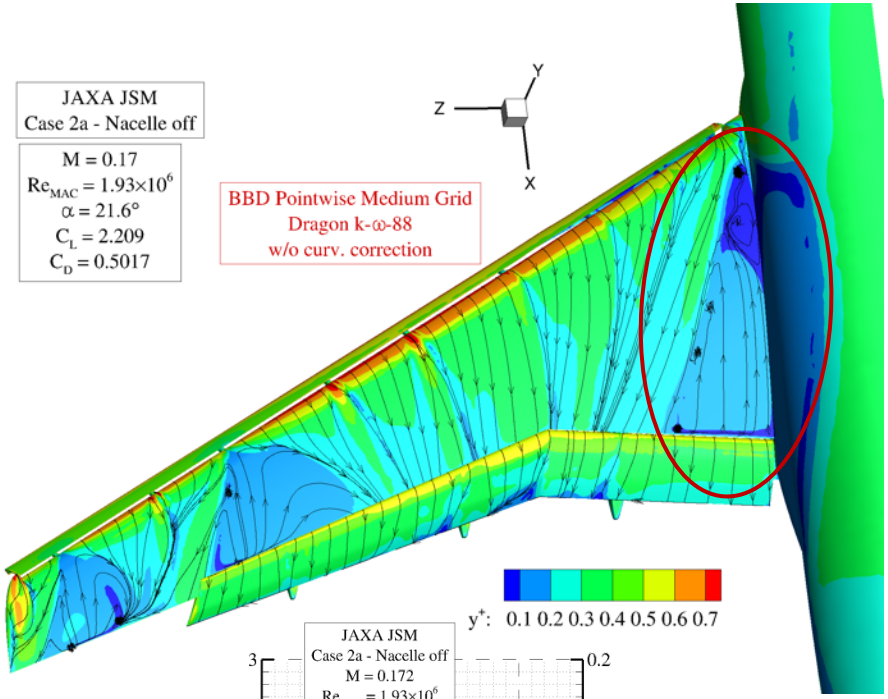




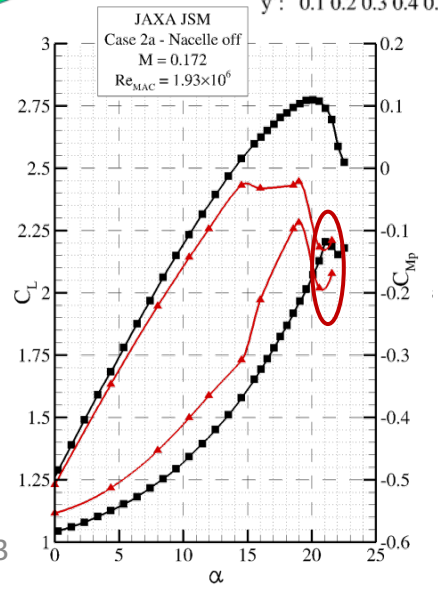


Excessive separation behind most OB slat track
Initial stall caused by massive flow separation behind slat track #6

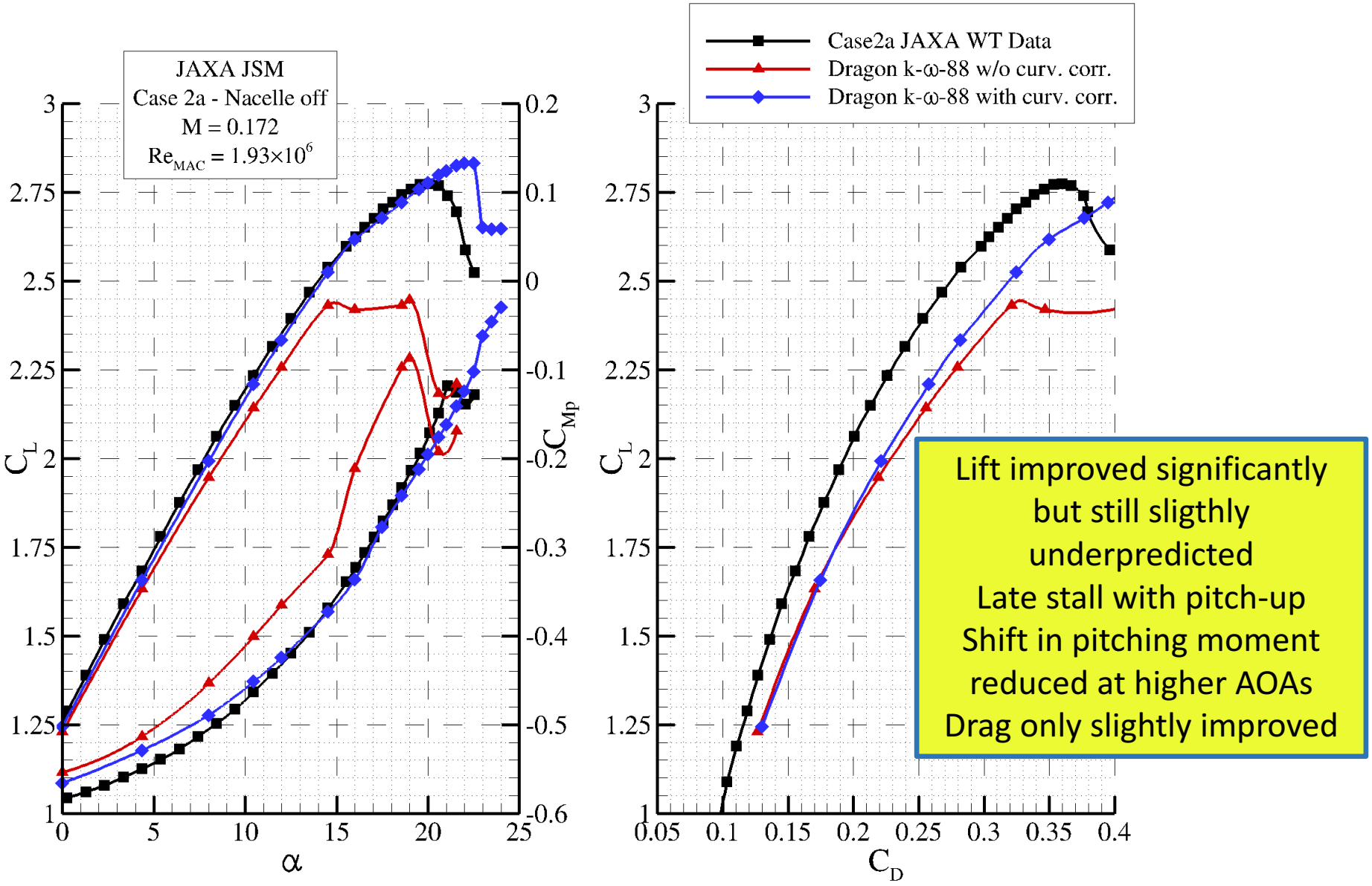
Early results: surface flow pattern at α = 21.6°



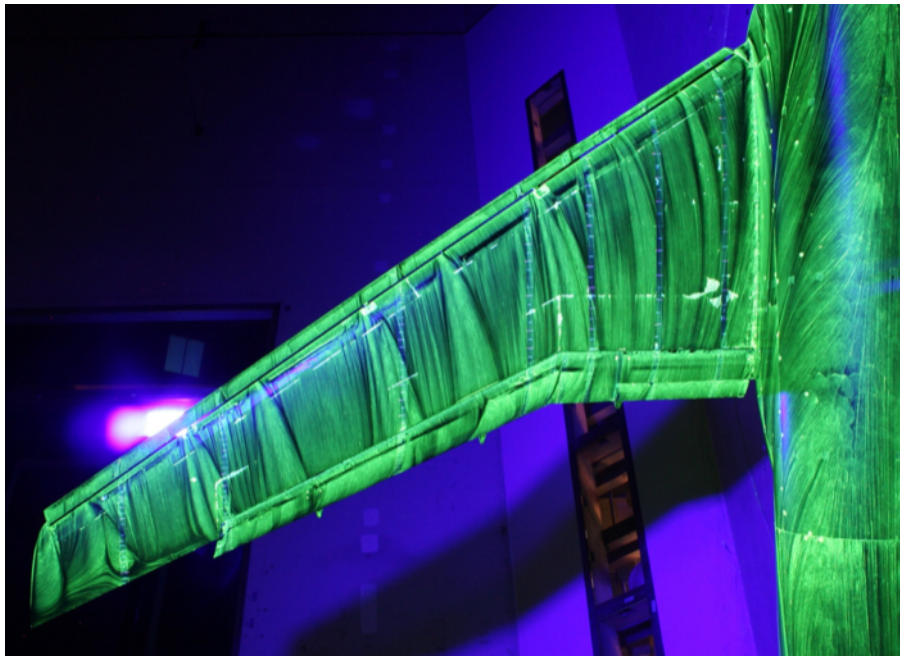
« Final » stall occurs at wing root
Need to prevent flow separation on OB wing
Early flow separation linked to excessive turbulence dissipation, ω, which can be reduced by introducing curvature correction

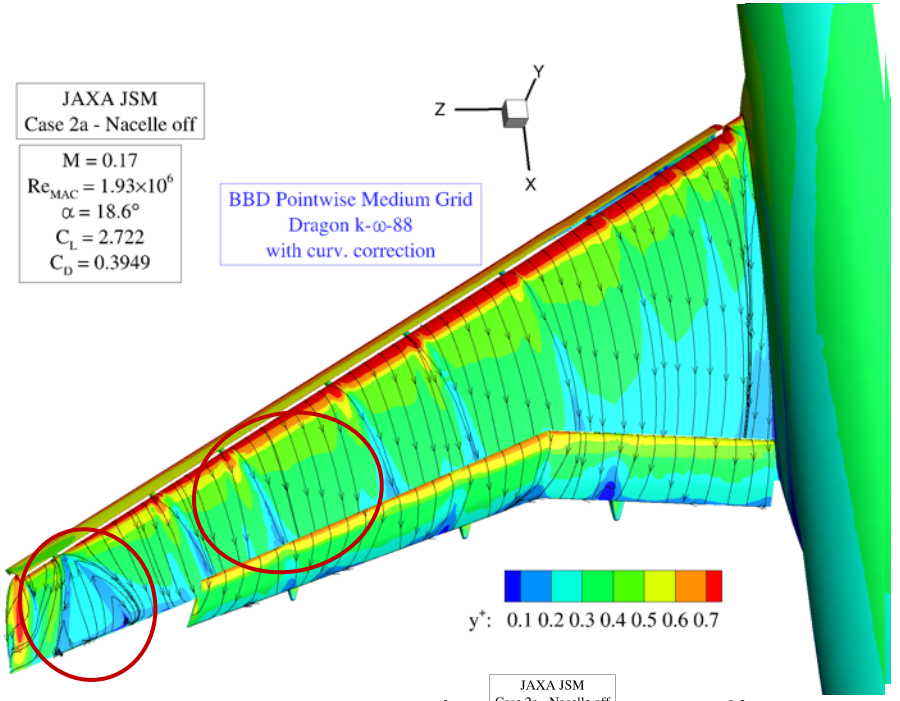


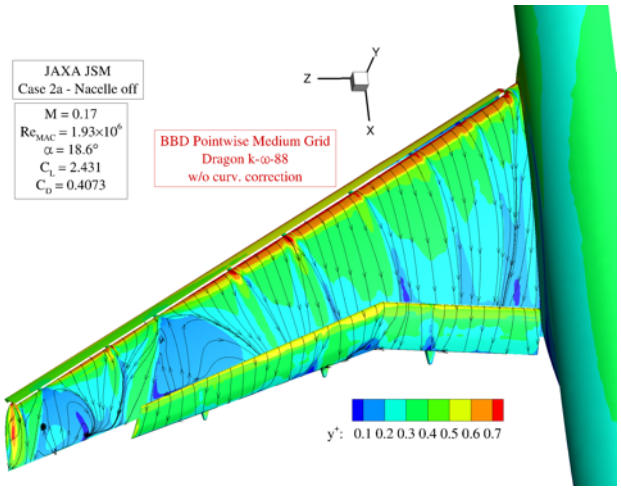
Curvature correction: forces & moments



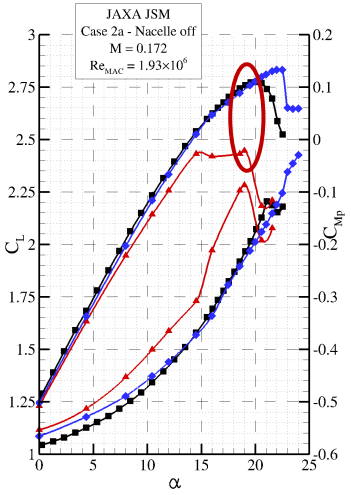
Curvature correction: surface flow pattern at α = 18.6°



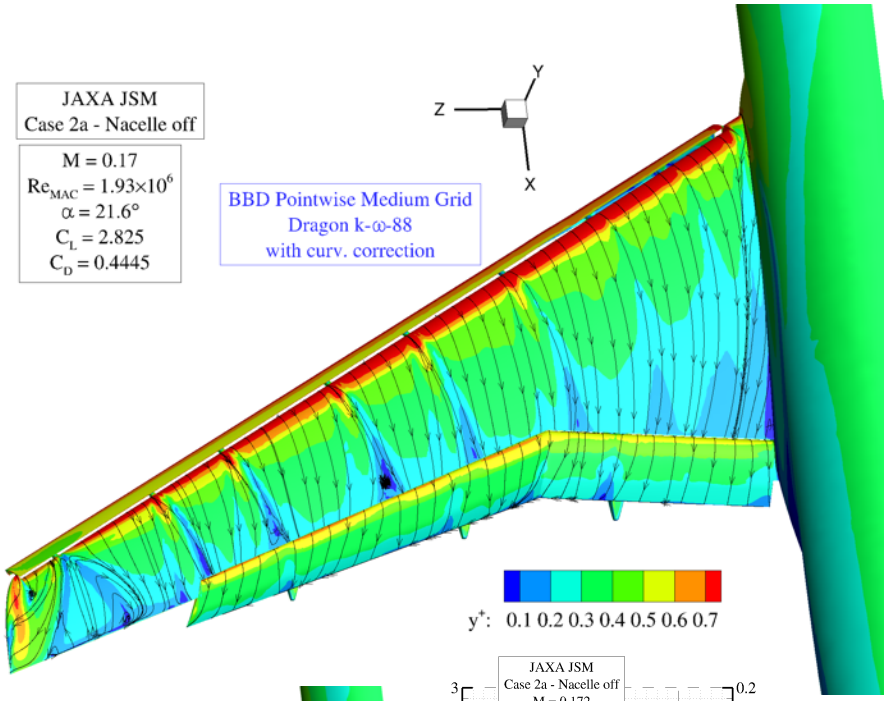


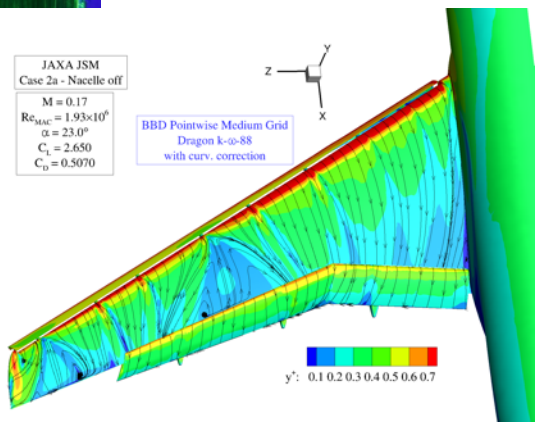


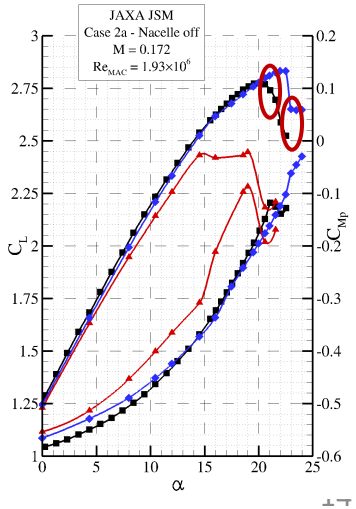
With curvature correction:
Reduced separation behind most OB slat track
Flow remains attached behind slat track #6



Curvature correction: surface flow pattern at α = 21.6°





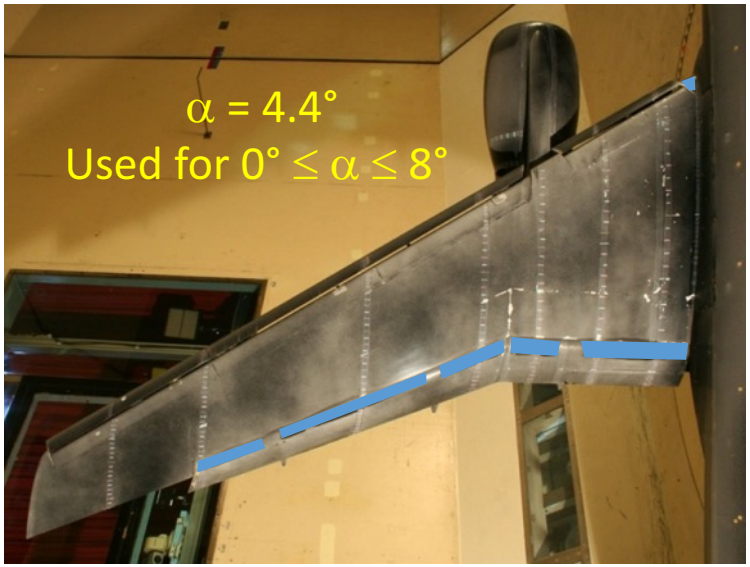


Wing root flow remains attached

Stall occurs at α = 23° behind slat track #5

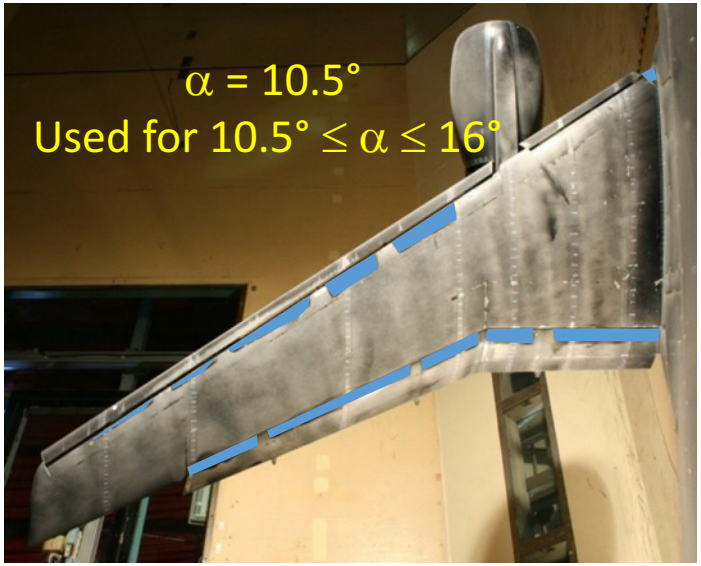
Need to increase lift and « trigger » stall at wing root

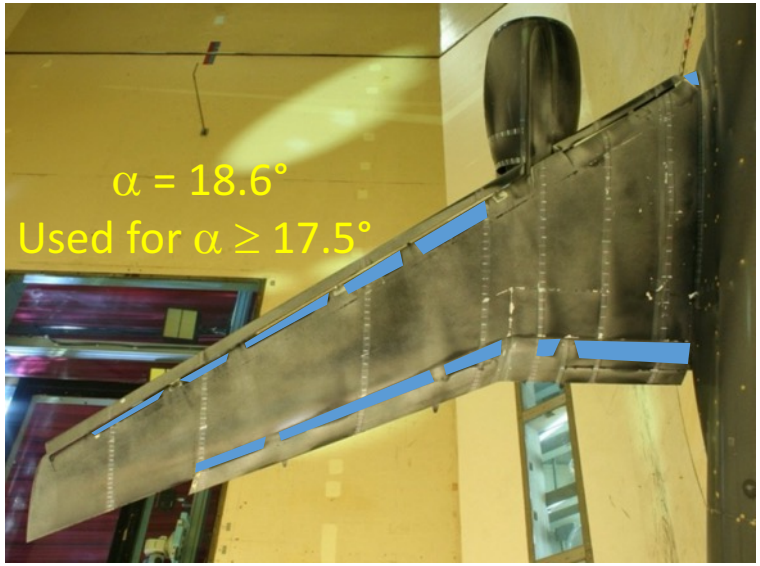
Impact of laminar-turbulent transition



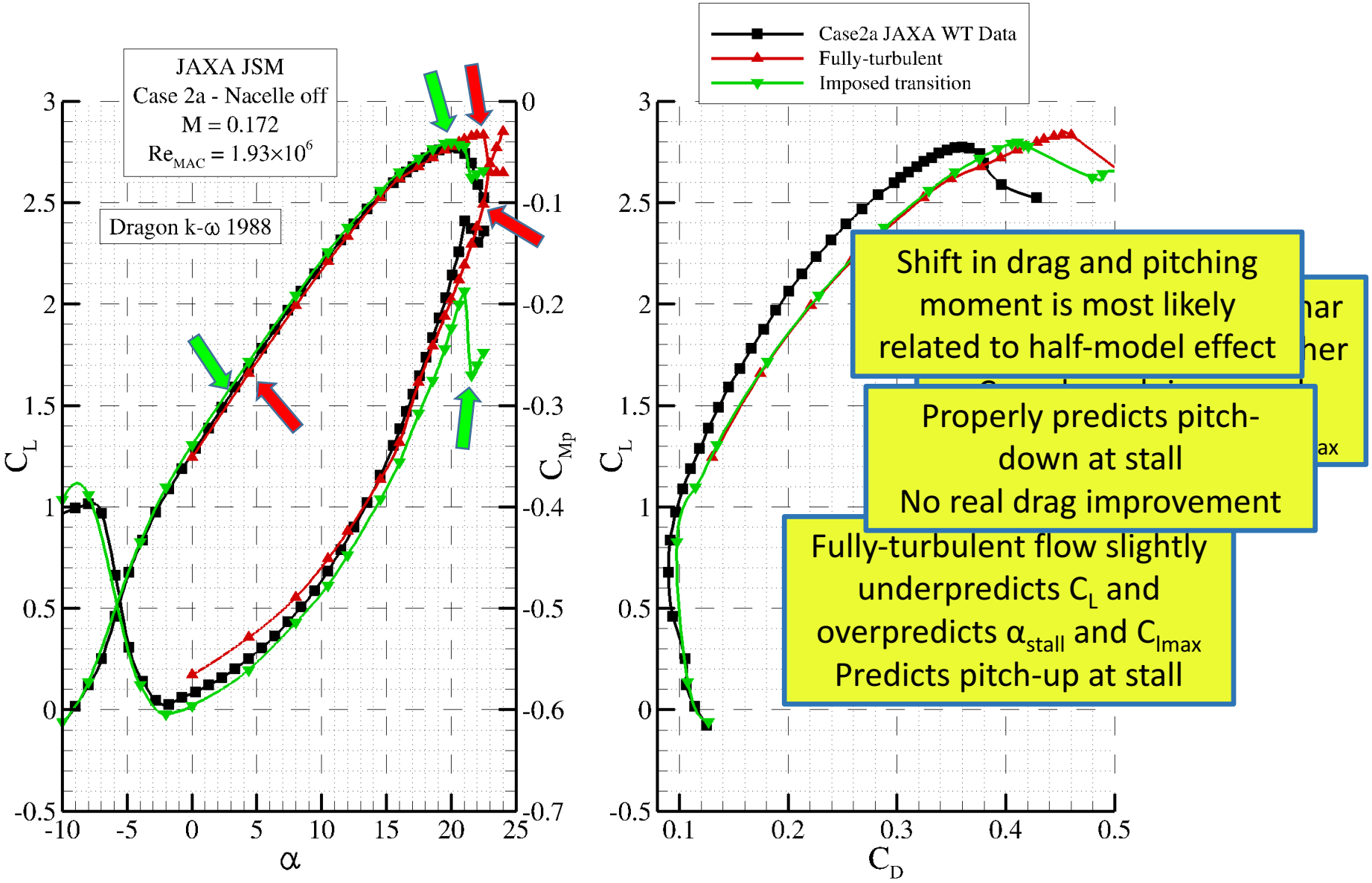
WT Reynolds number is low
Significant extents of laminar flow are expected

Transition imposed in Dragon (not predicted)
Based on WT transition detection
No transition on slats
Inboard WUSS fully-turbulent even w/o nacelle
Laminar flow on fixed IB leading edge
Transition location on LS same as on US

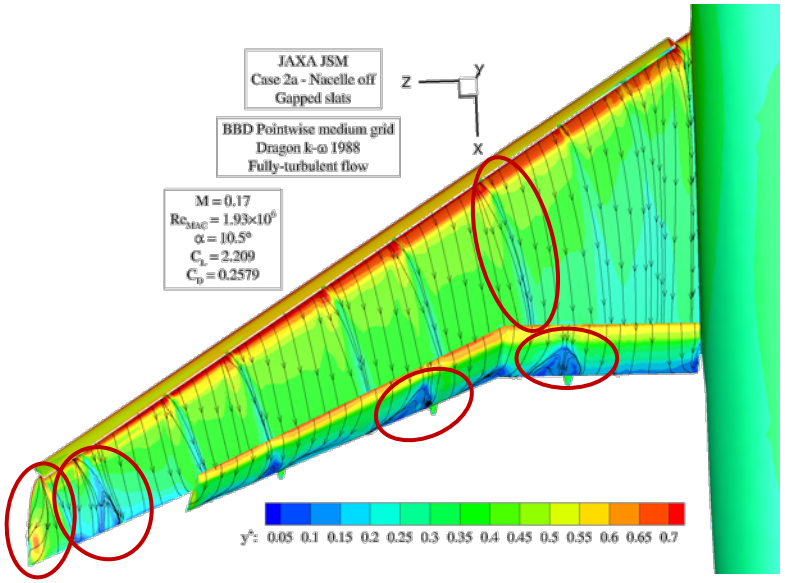


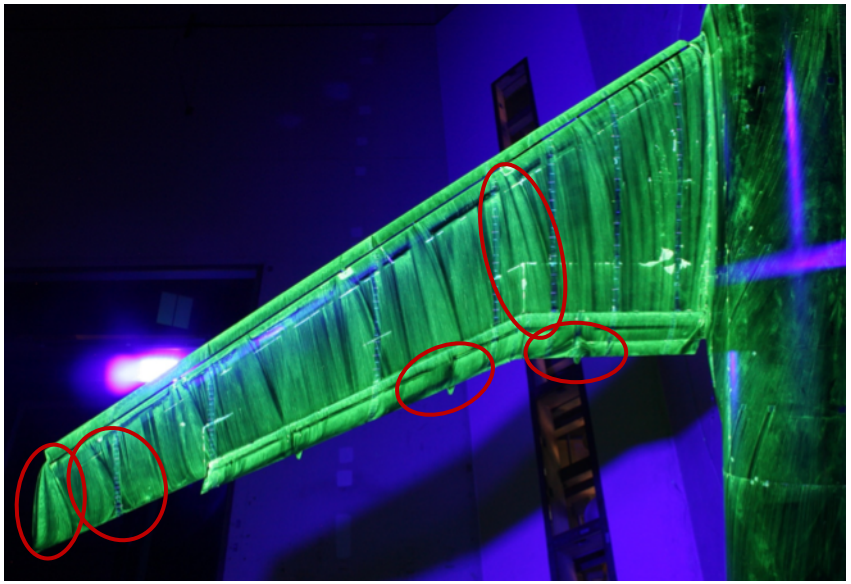


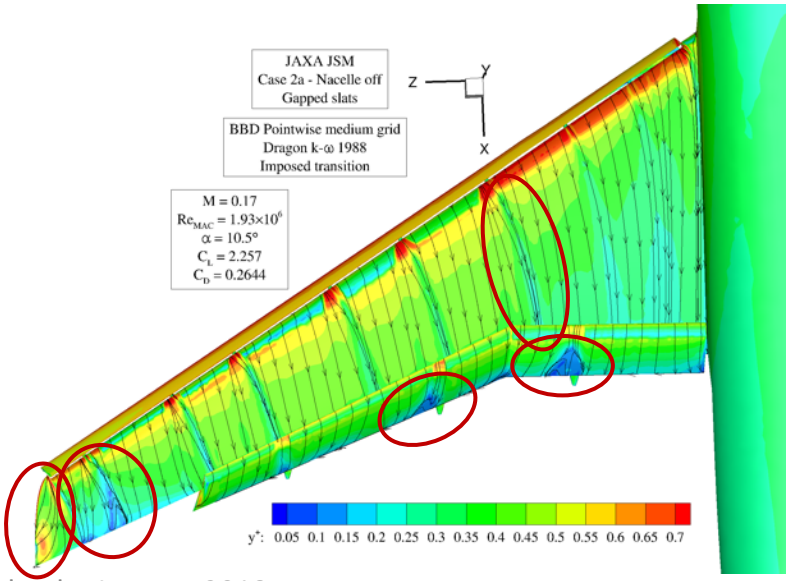
Transition influence: forces & moments



Transition influence: surface flow pattern at α = 10.5°



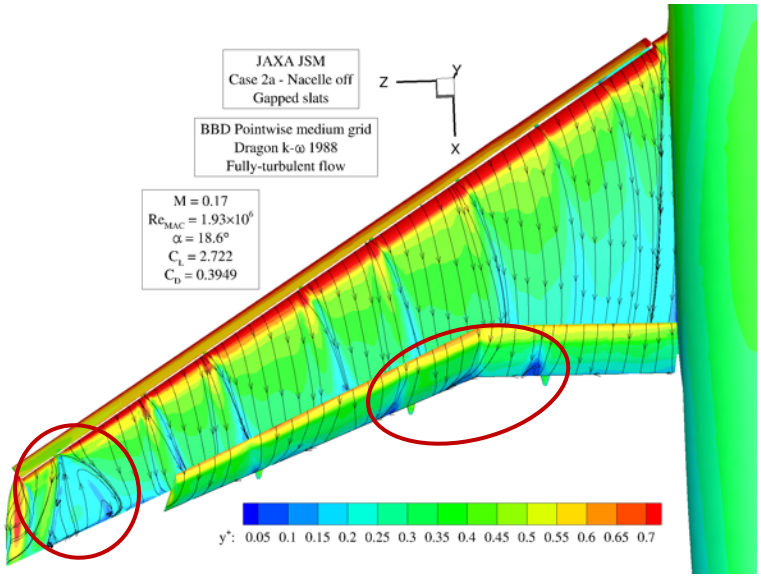


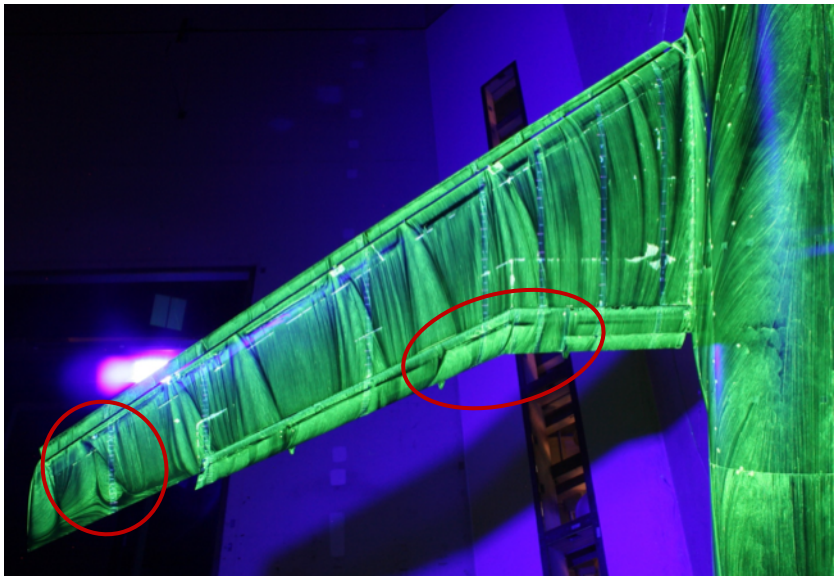


Flow pattern well predicted overall:

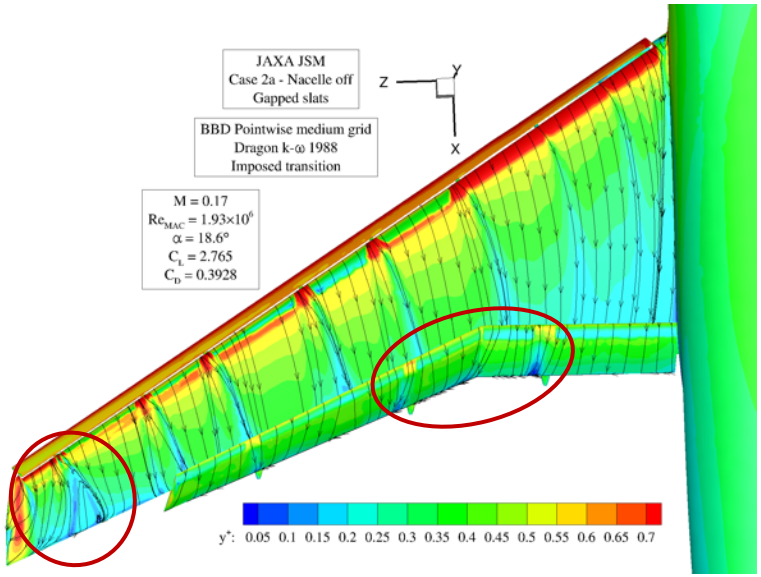
- Flow separation behind FTFs
- Flow separation behind most-OB slat track
- Wingtip separation
- Slat tracks vortices (lower y^+)

Transition influence: surface flow pattern at α = 18.6°

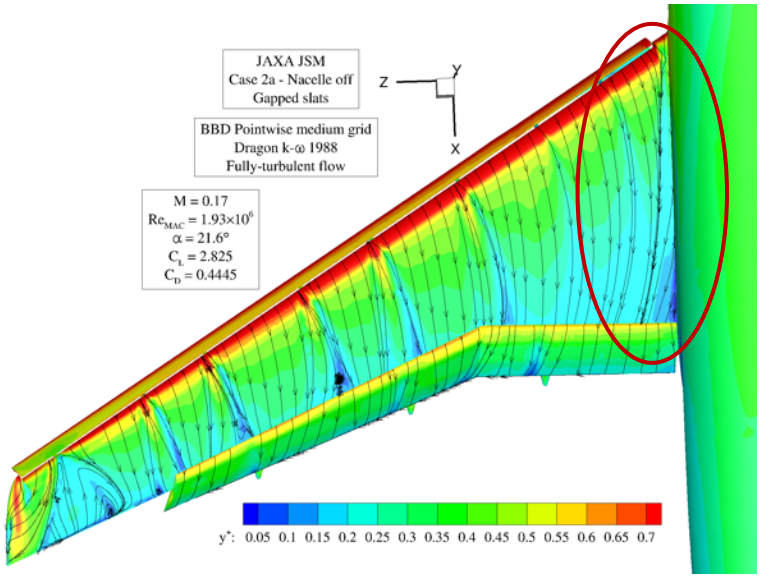


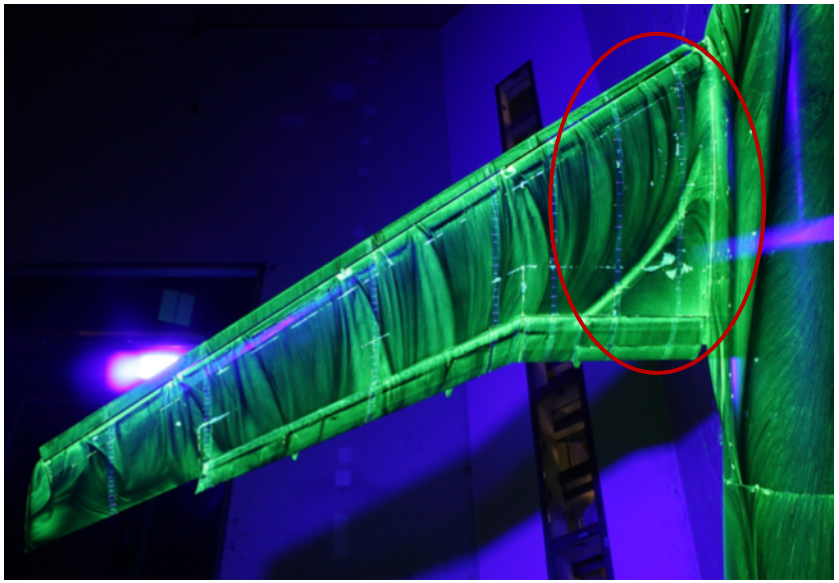


FT solution overpredicts extent of flow separation behind most-OB slat track and FTFs

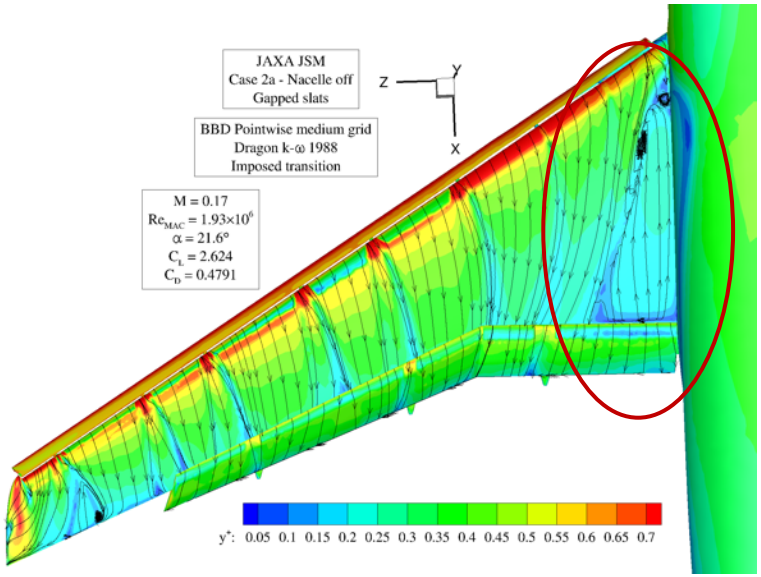


Transition influence: surface flow pattern at α = 21.6°

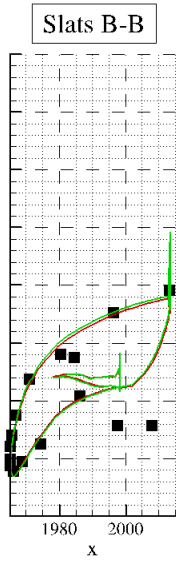


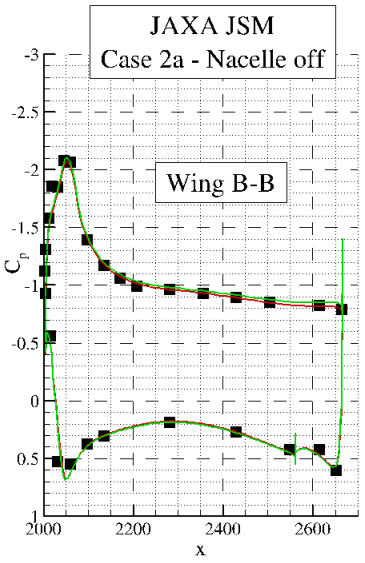


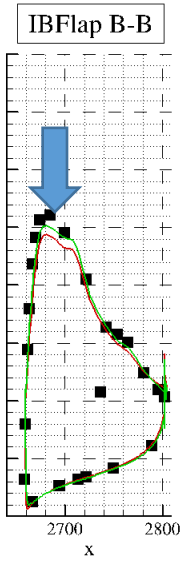
FT solution does not predict IB separation
Prediction improved with laminar flow on fixed IB LE

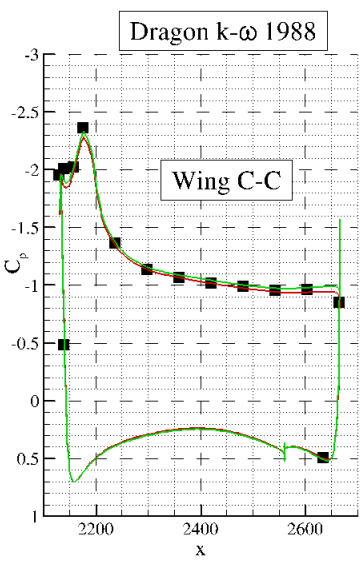


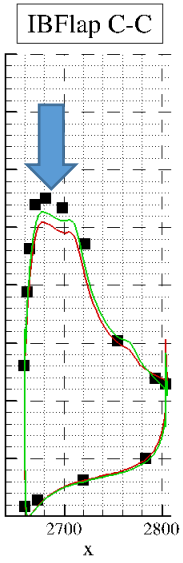
JAXA JSM results
Transition influence: pressure distributions at α = 4.4°

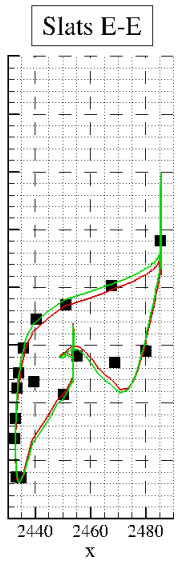


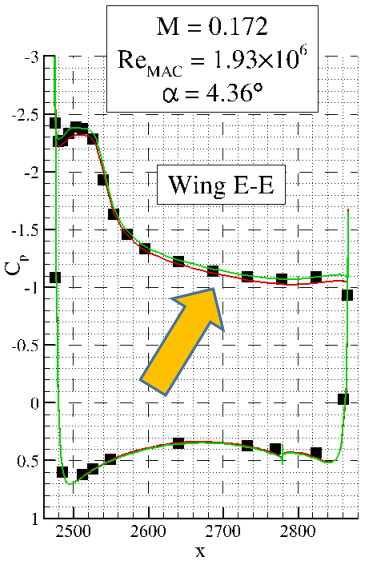


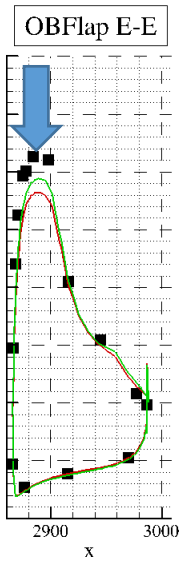


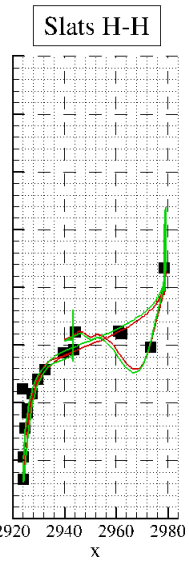


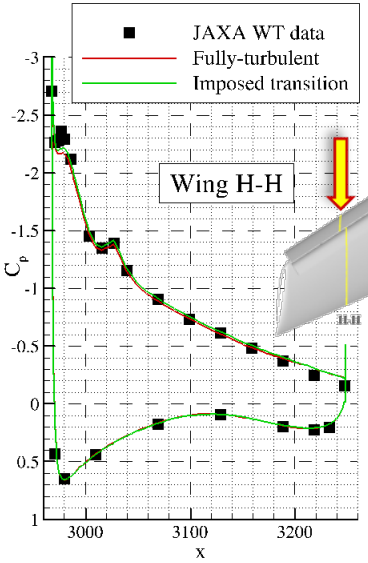


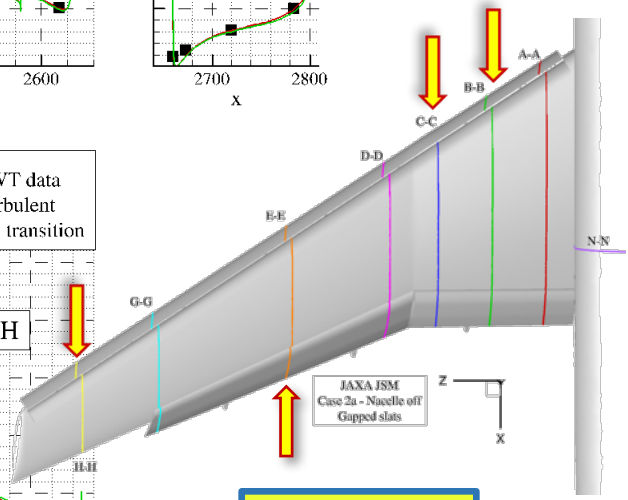










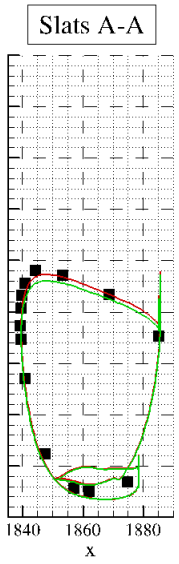


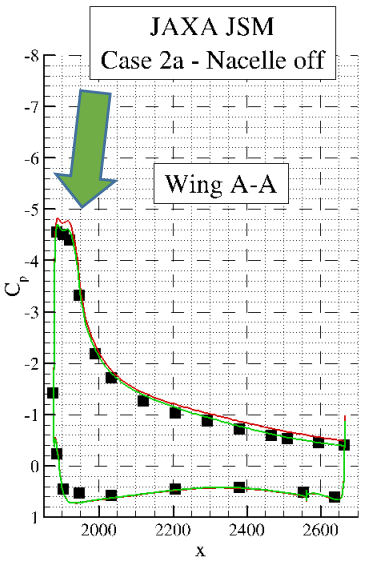
on flaps

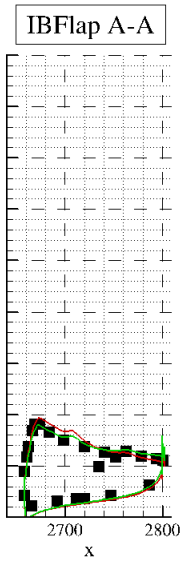
C_ps closer to WT data with presence of

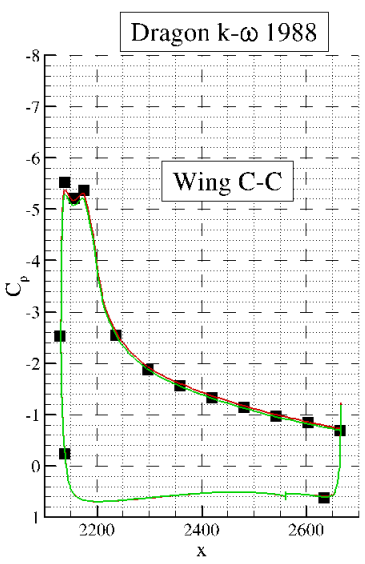
and on wing

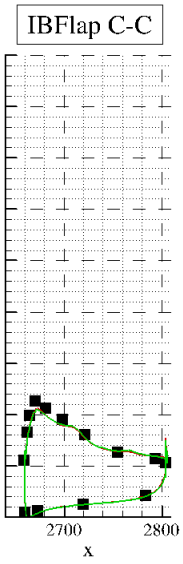
Transition influence: pressure distribution at stall (α = 20.6°)

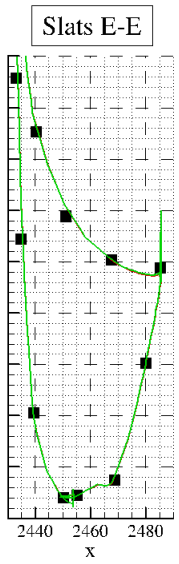


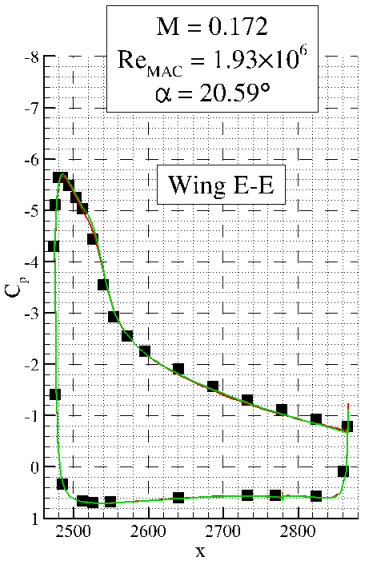


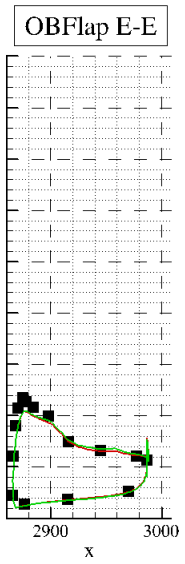


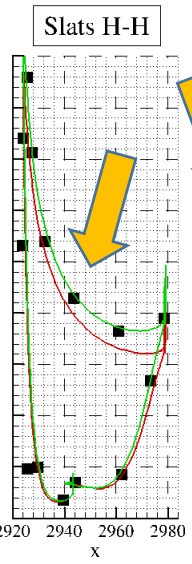


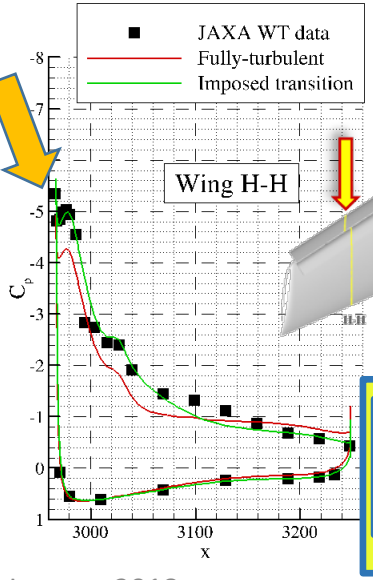


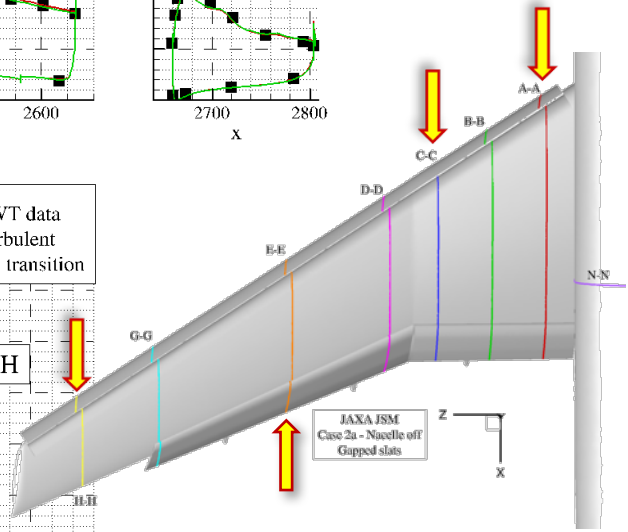








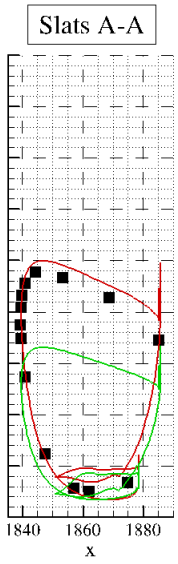


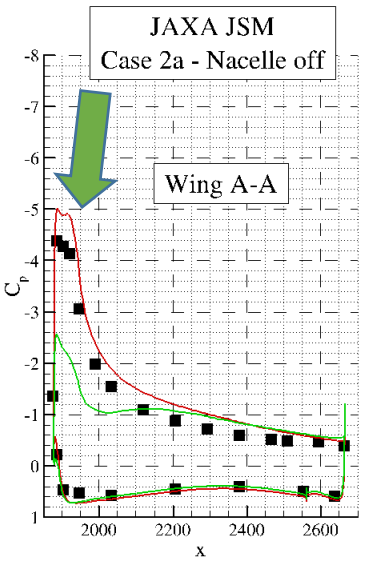


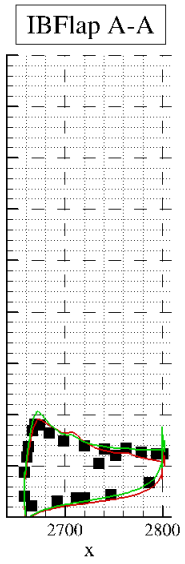
Much improved C_ps on OB WUSS and slat

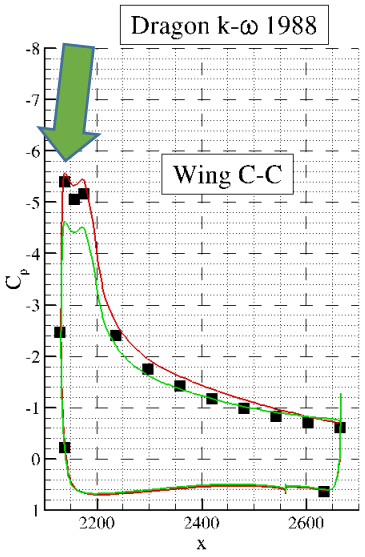
IB fixed LE

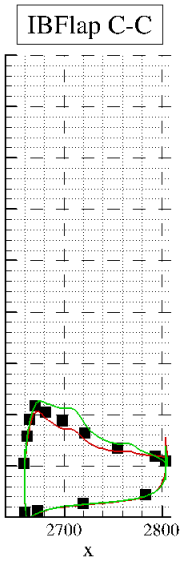
Transition influence: post-stall pressure dist. (α = 21.6°)

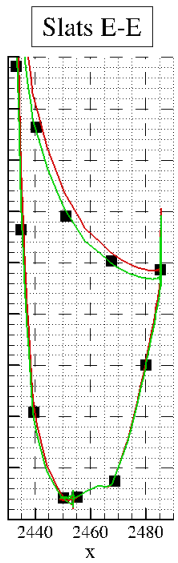


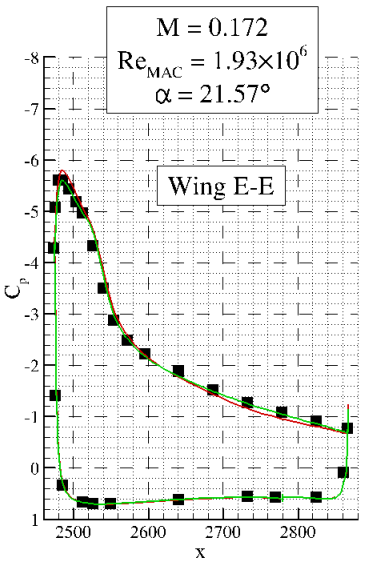


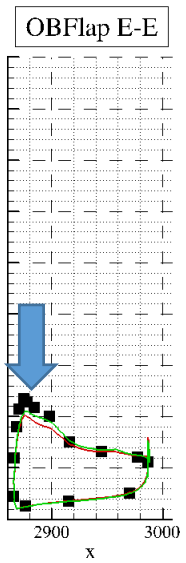


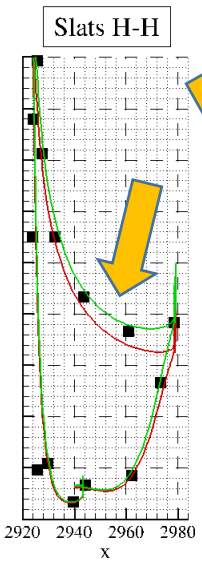


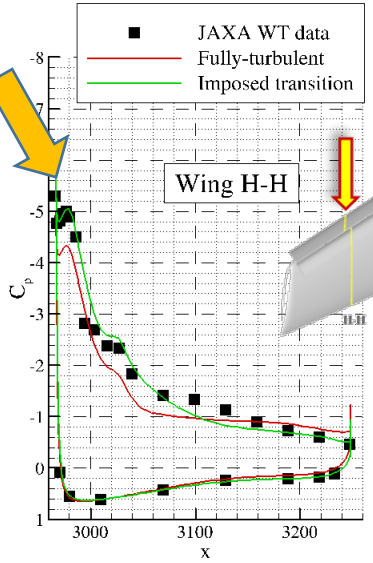


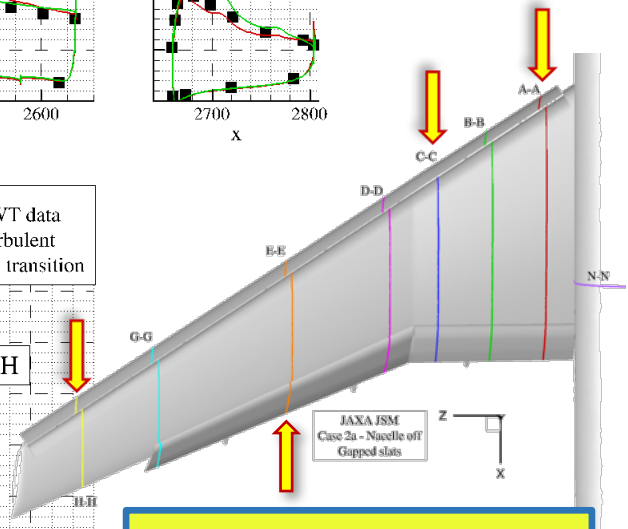






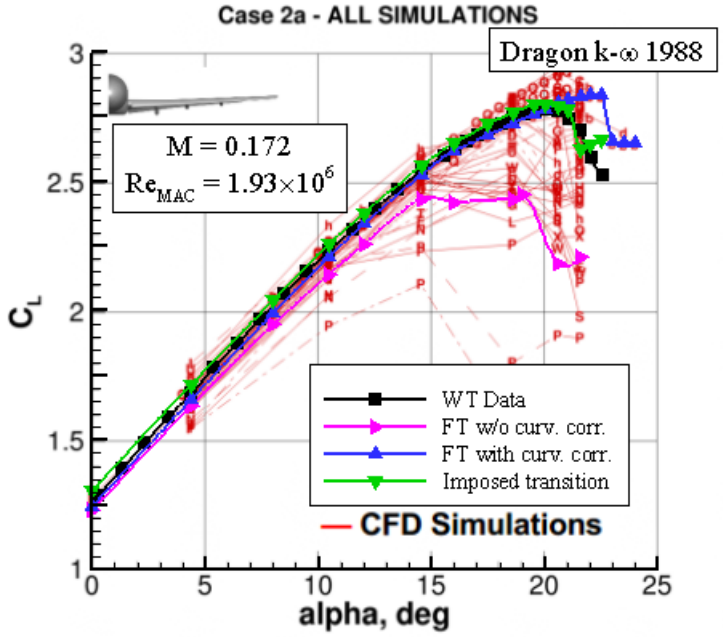


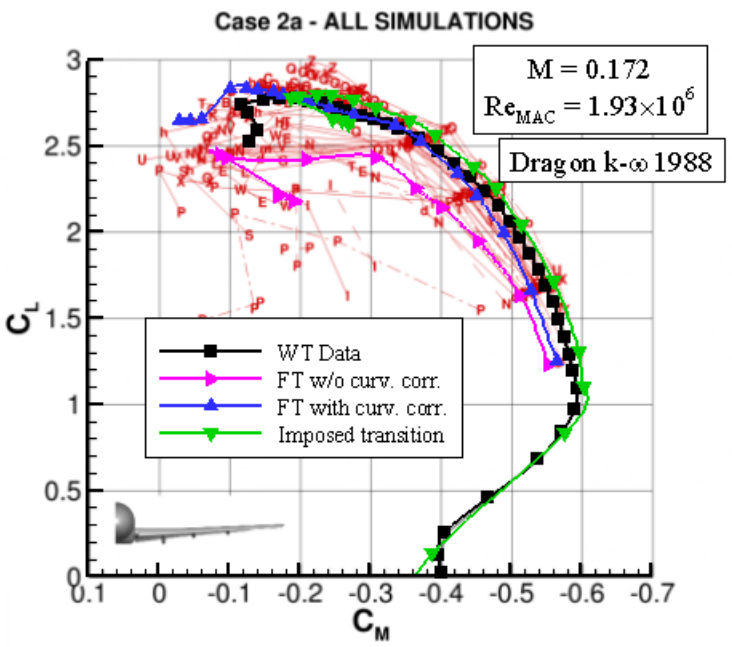


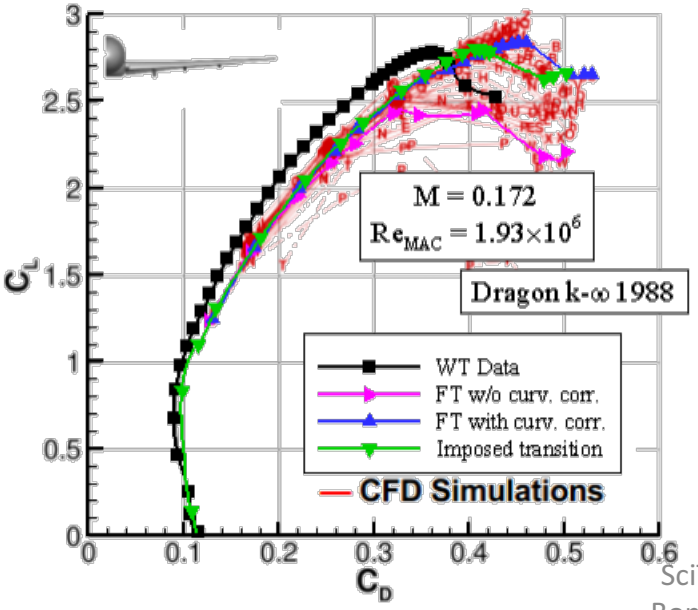


IB stall is too abrupt
Laminar flow extent on IB fixed LE should be reduced

Dragon vs. other codes: forces & moment

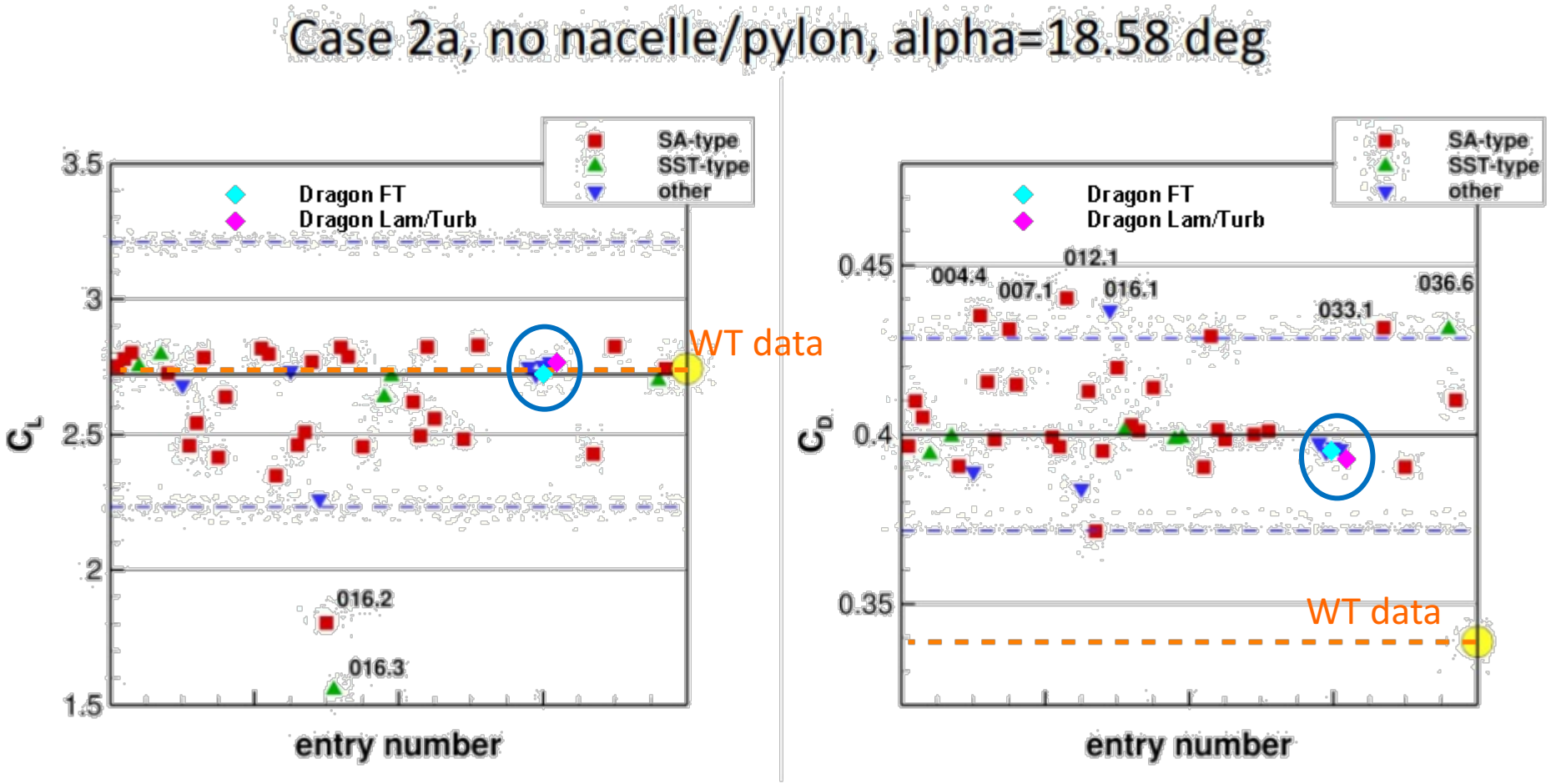






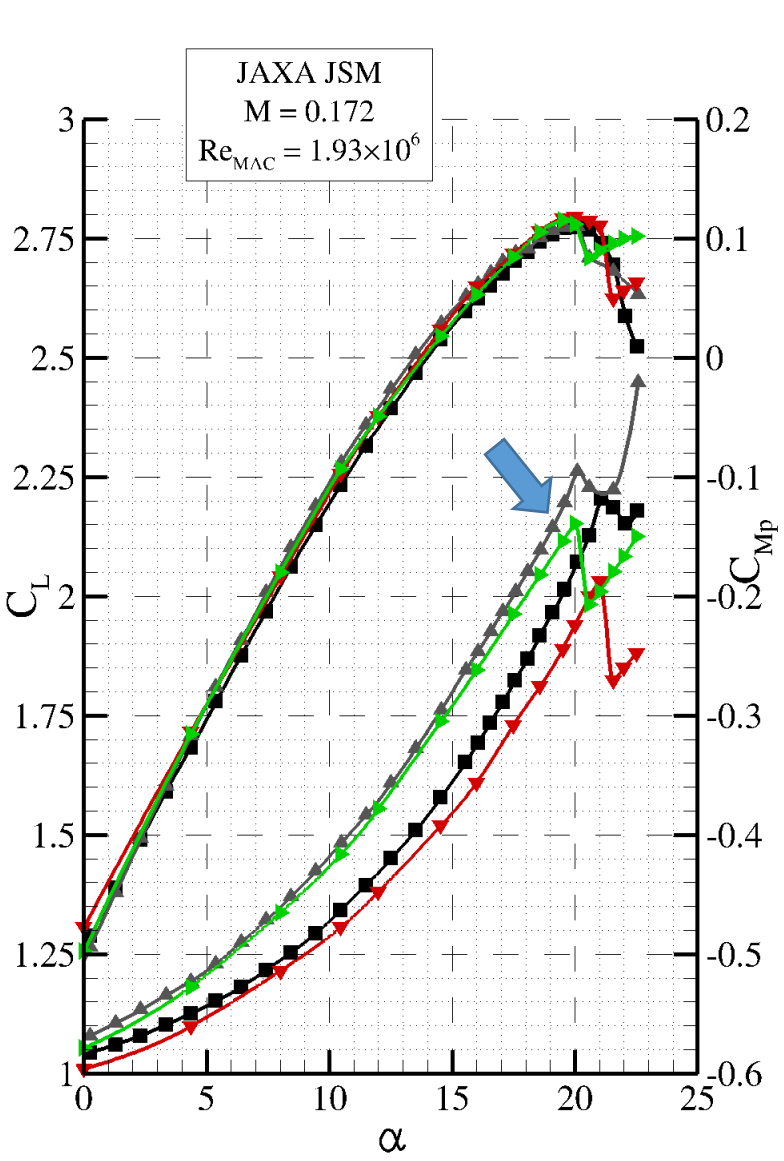
Large scatter in lift and pitching moment
Solution w/o curvature correction is still within the range of results presented
Solutions with curvature correction are among those providing the best agreement with the WT data
All solutions overpredict drag

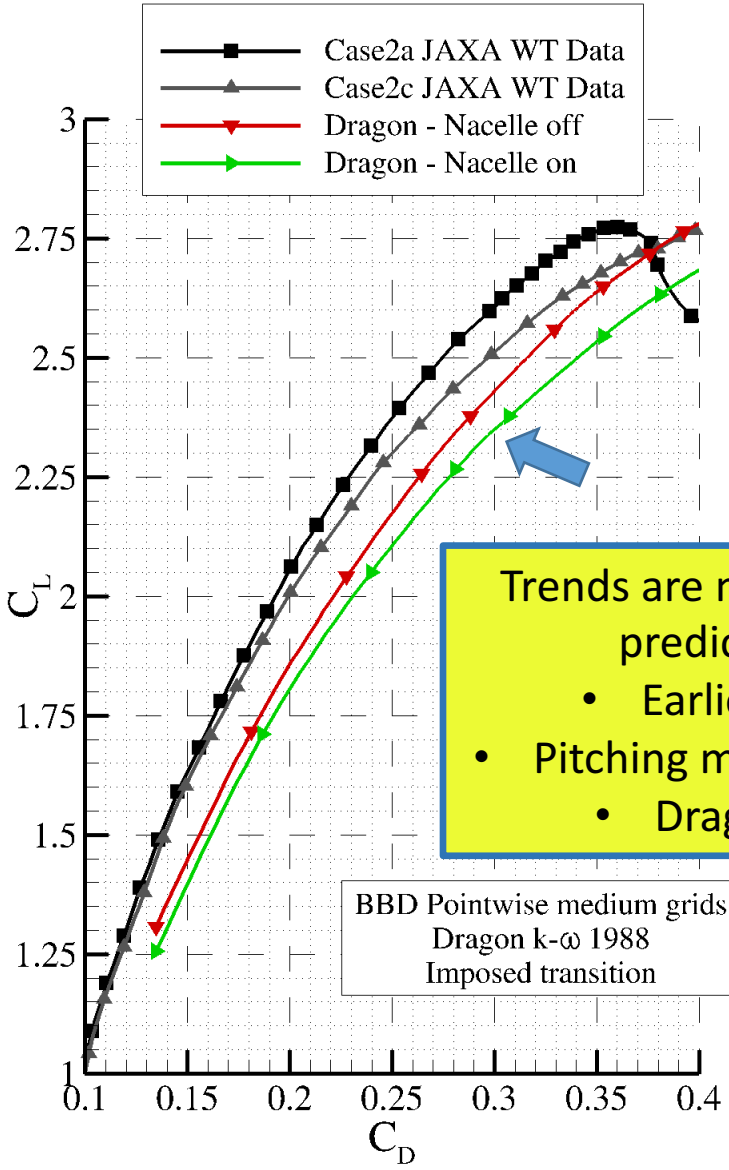
Dragon vs. other codes: lift and drag at α = 18.6°



Lift predicted by Dragon is very close to average of all CFD data and to WT data
Drag is also close to the CFD average and closer to the WT data than most

Nacelle installation: forces & moments

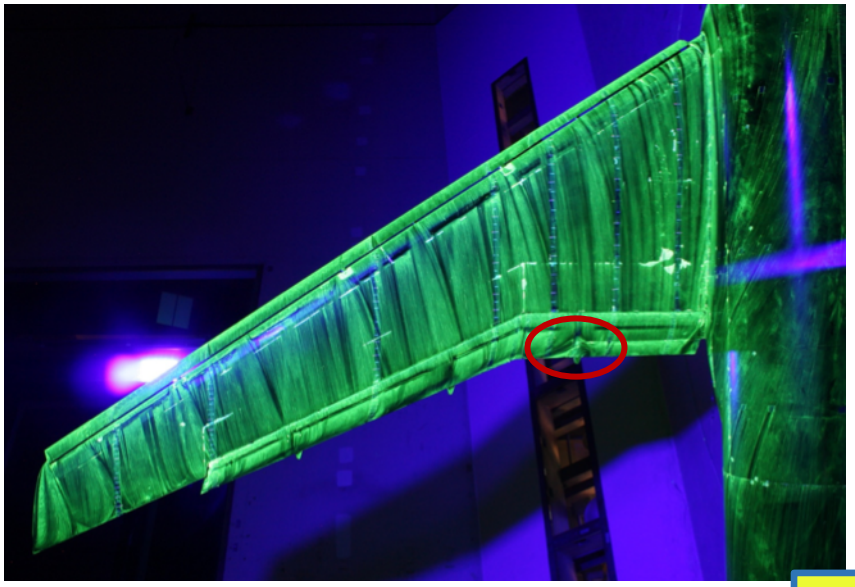


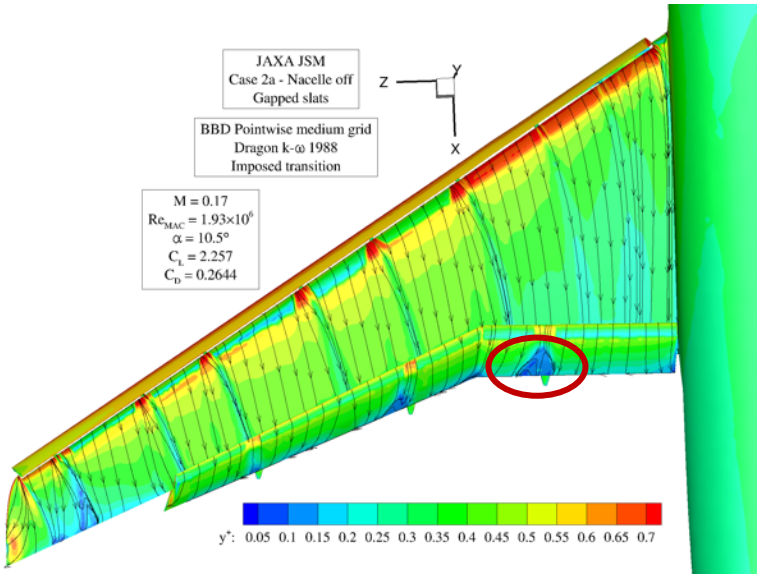


Trends are mostly well predicted:

- Earlier stall
- Pitching moment shift
- Drag shift

Nacelle installation: surface flow pattern at α = 10.5°

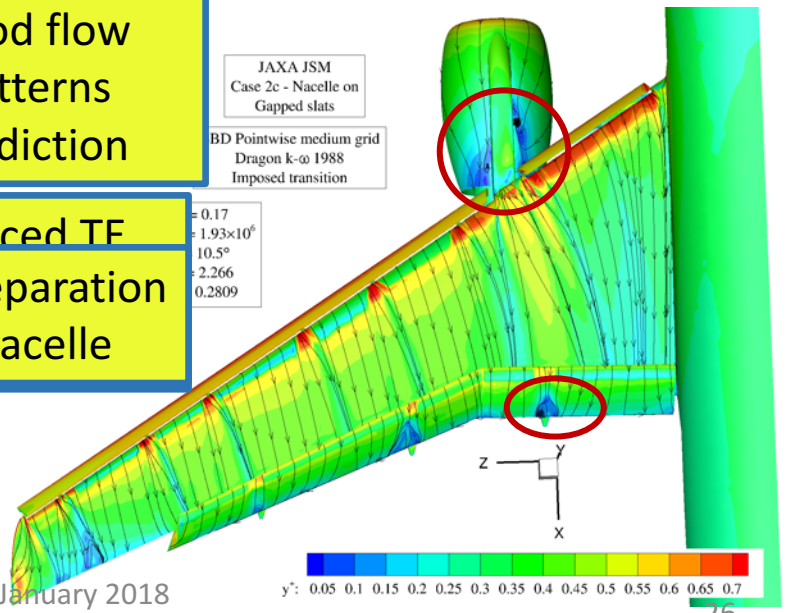




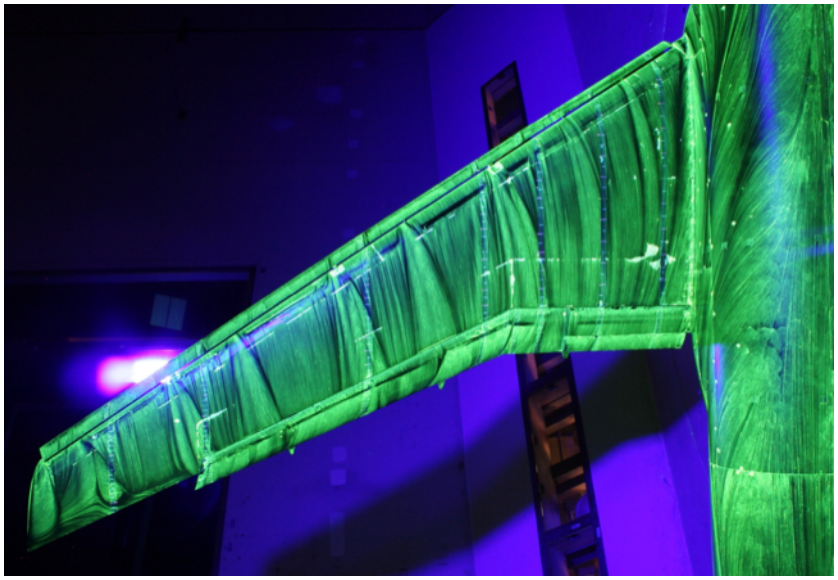
Good flow patterns prediction

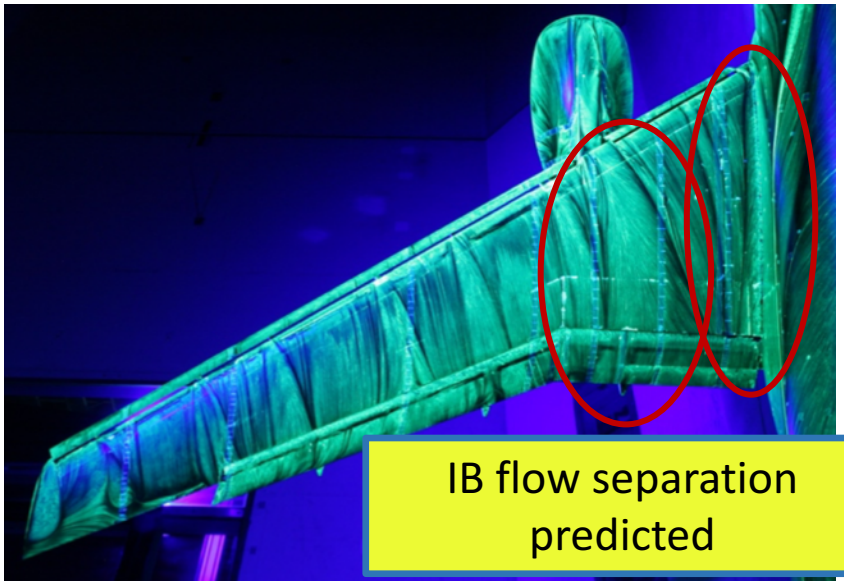
Reduced TE

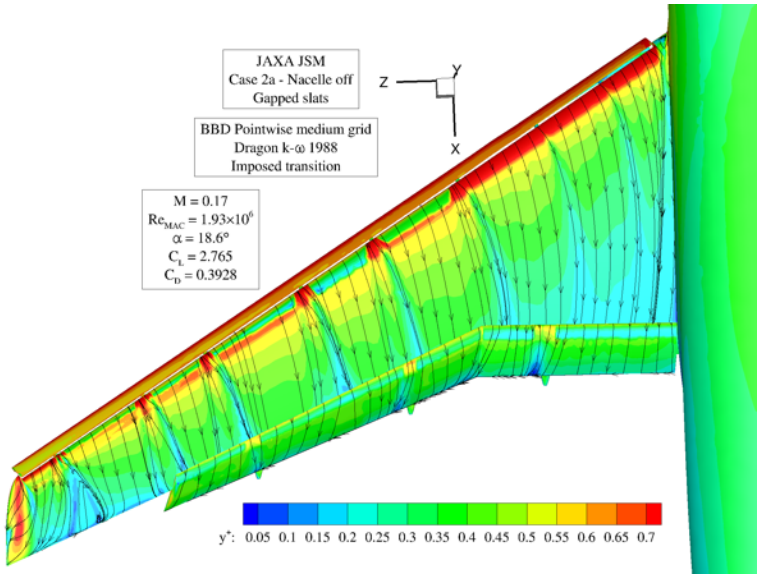
Flow separation on nacelle

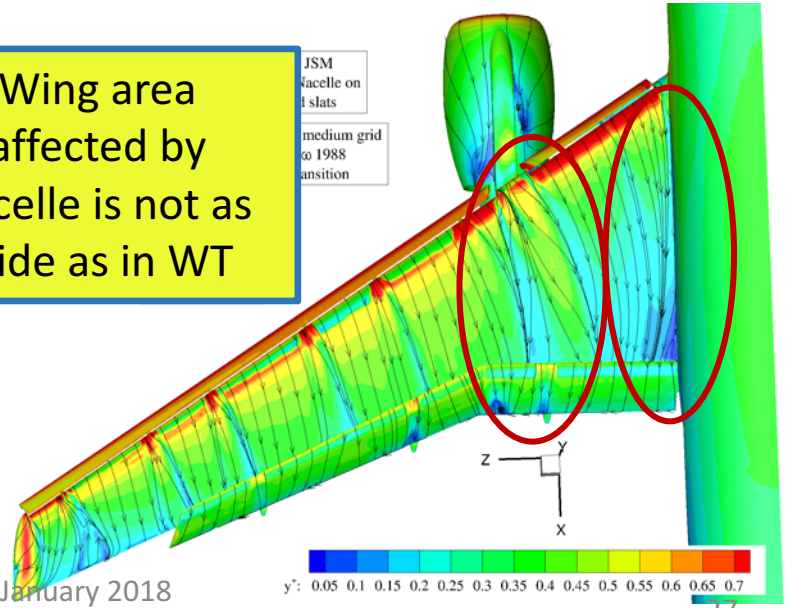


Nacelle installation: surface flow pattern at α = 18.6°



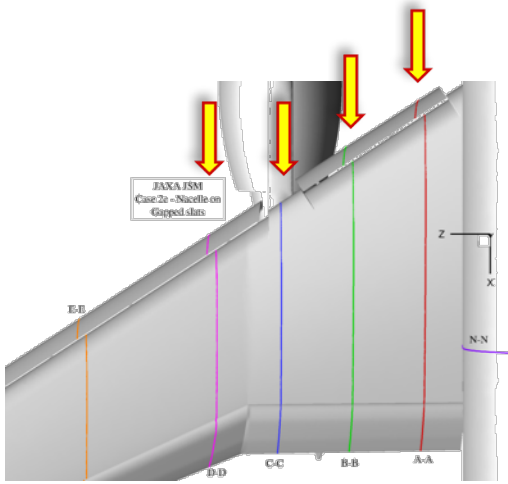


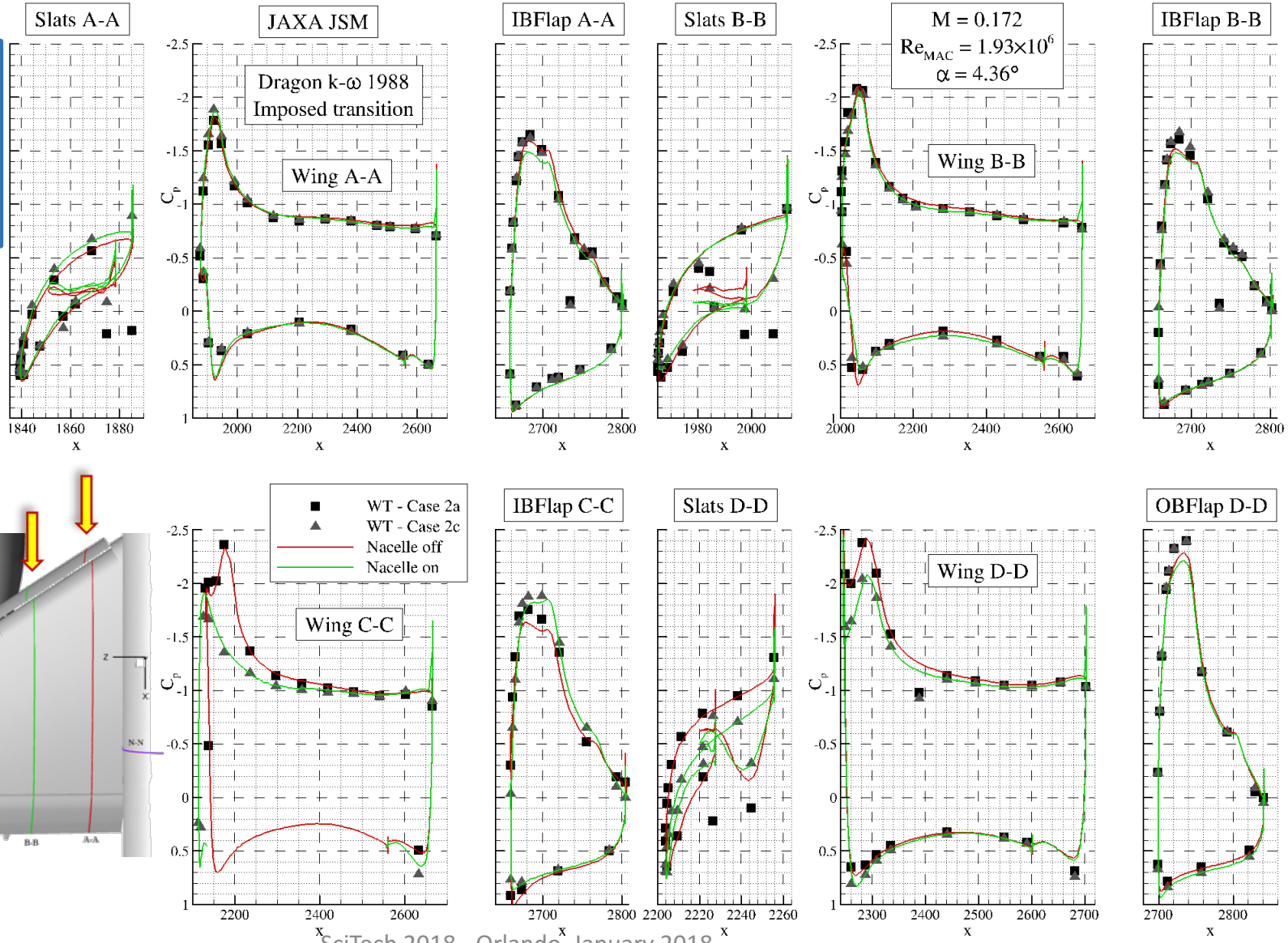




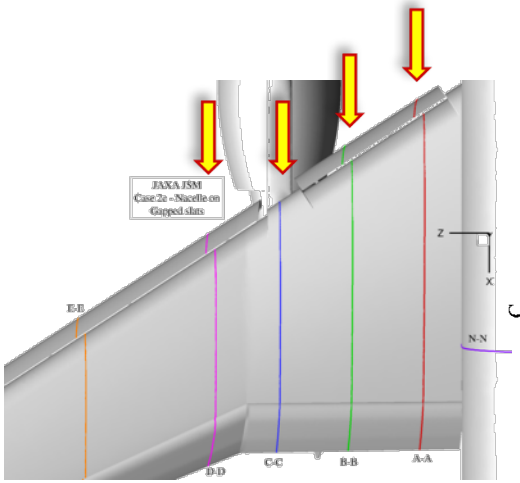
Nacelle installation: pressure distributions at α = 4.4°

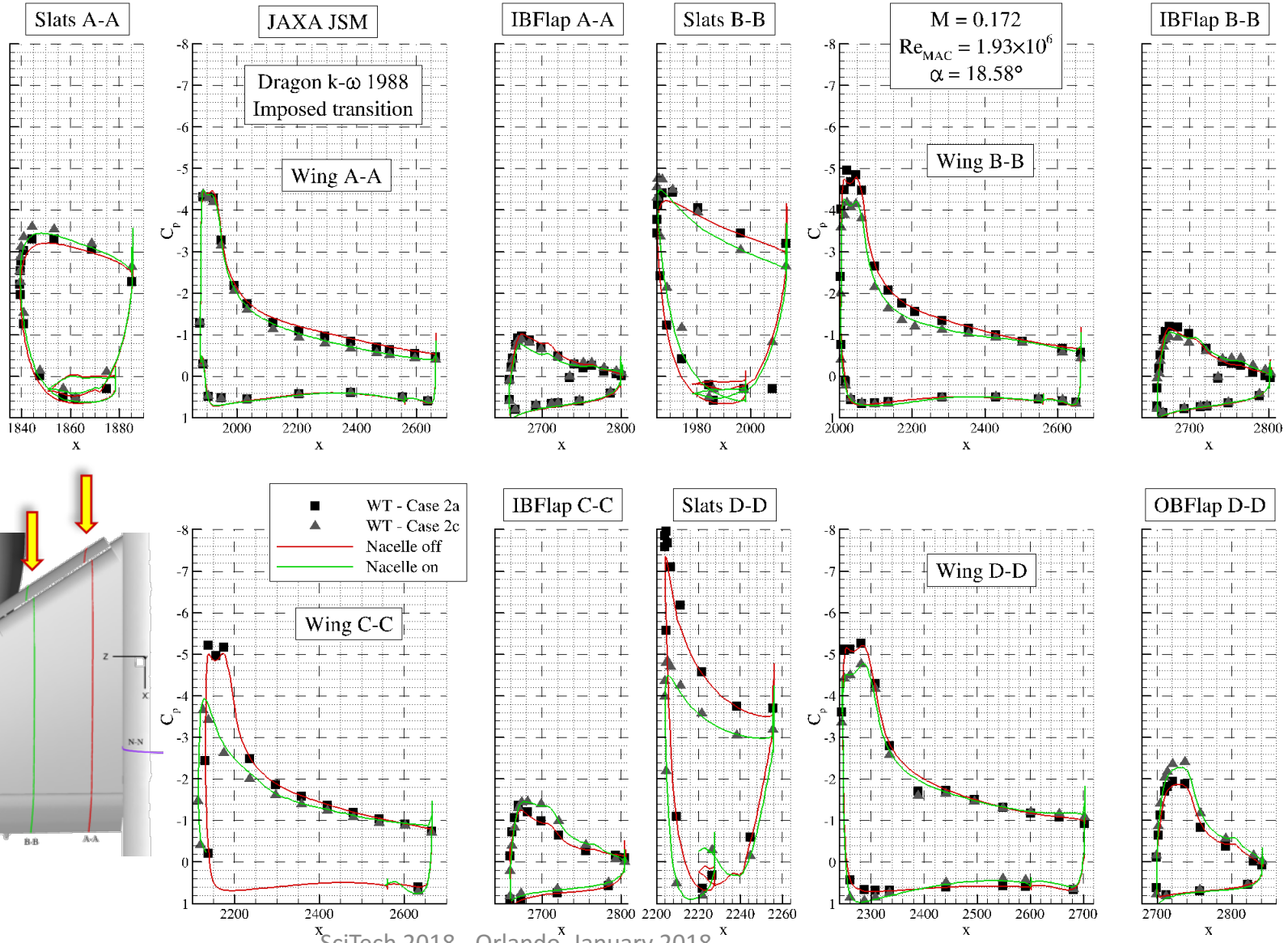
Impact of nacelle on C_ps is well predicted



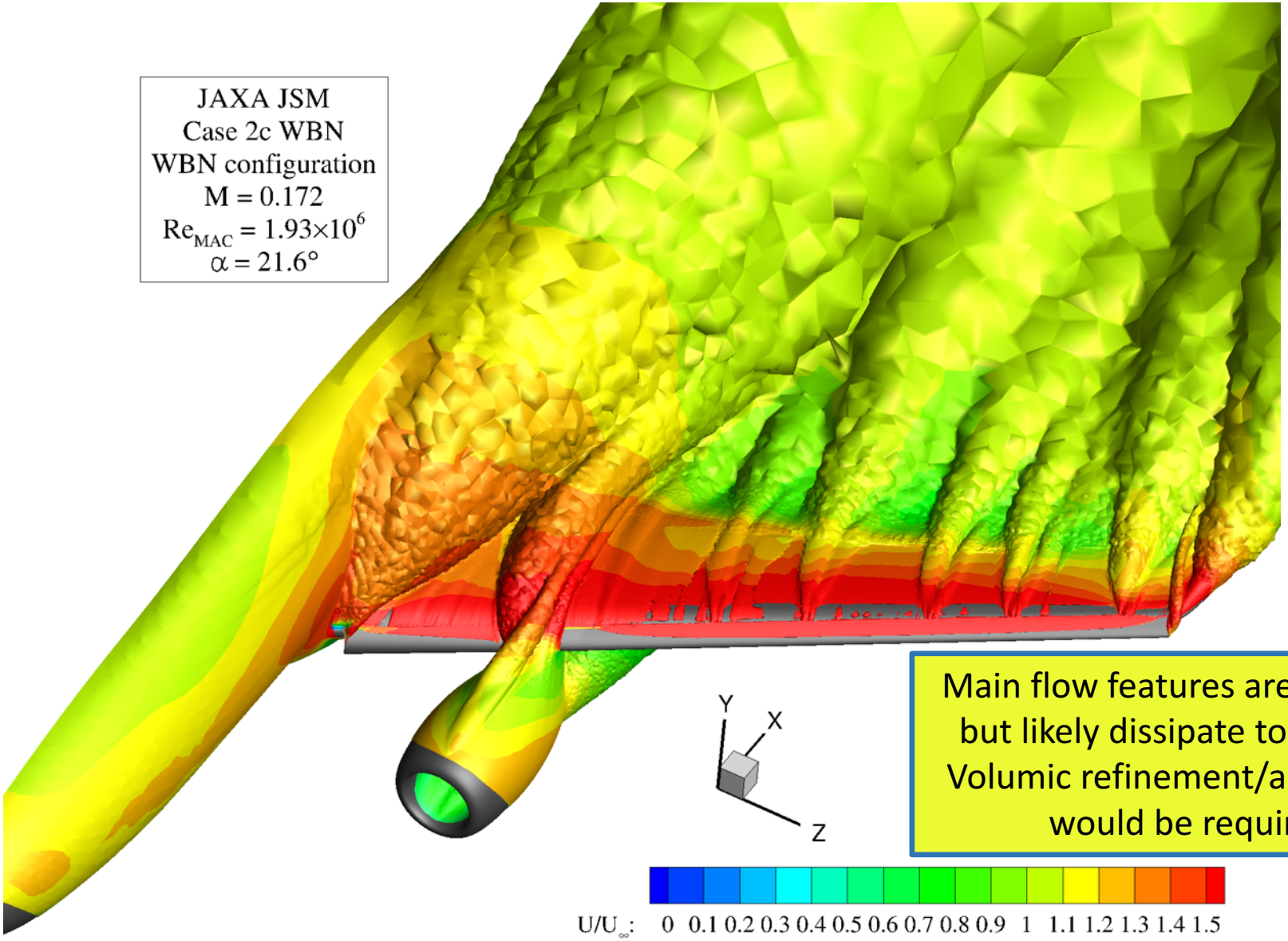


Nacelle installation: pressure distributions at α = 18.6°



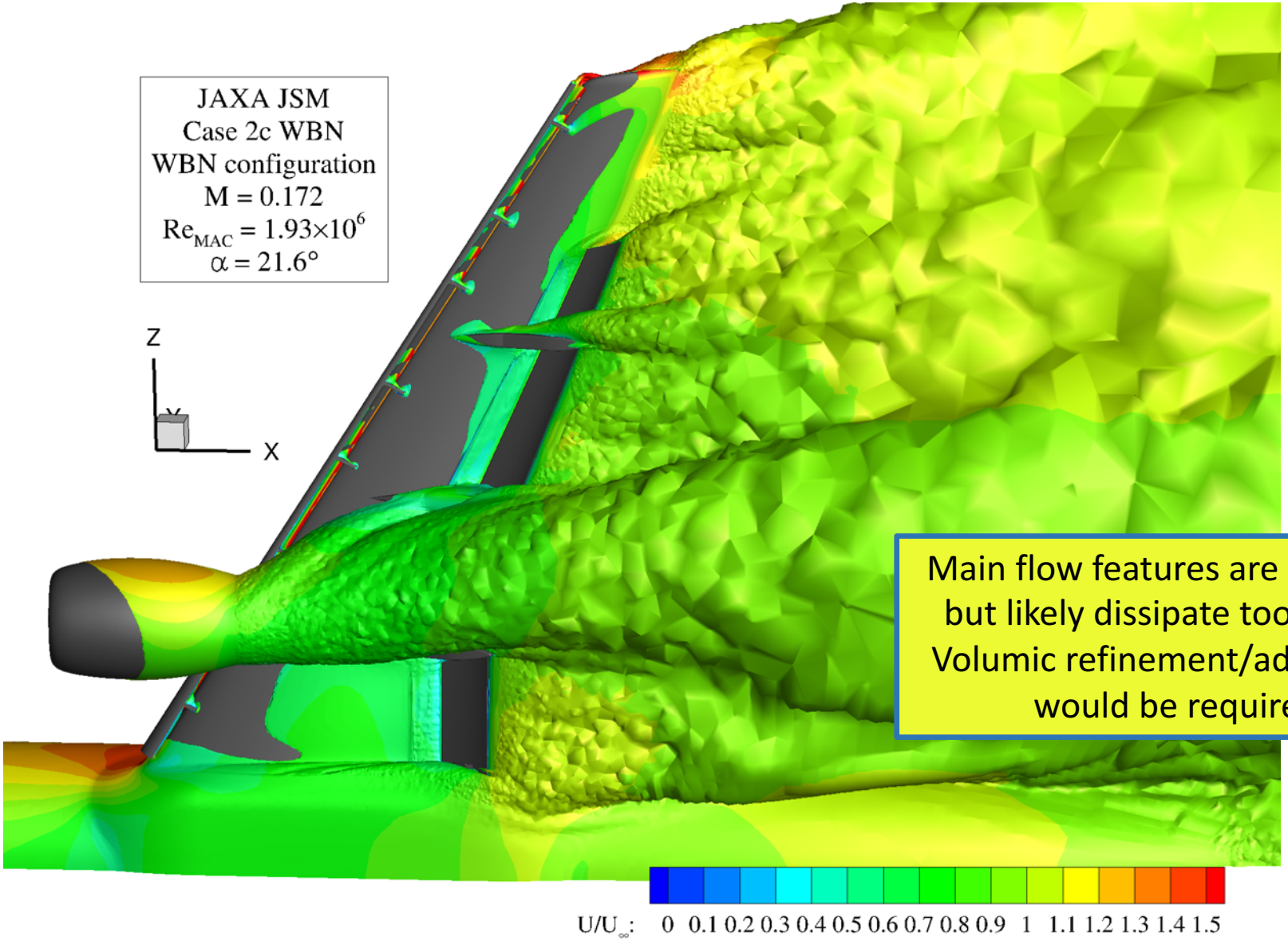


Nacelle-on configuration: volume plots



Main flow features are captured but likely dissipate too quickly
Volumic refinement/adaptation would be required

Nacelle-on configuration: volume plots



Main flow features are captured but likely dissipate too quickly
Volumic refinement/adaptation would be required

Conclusions

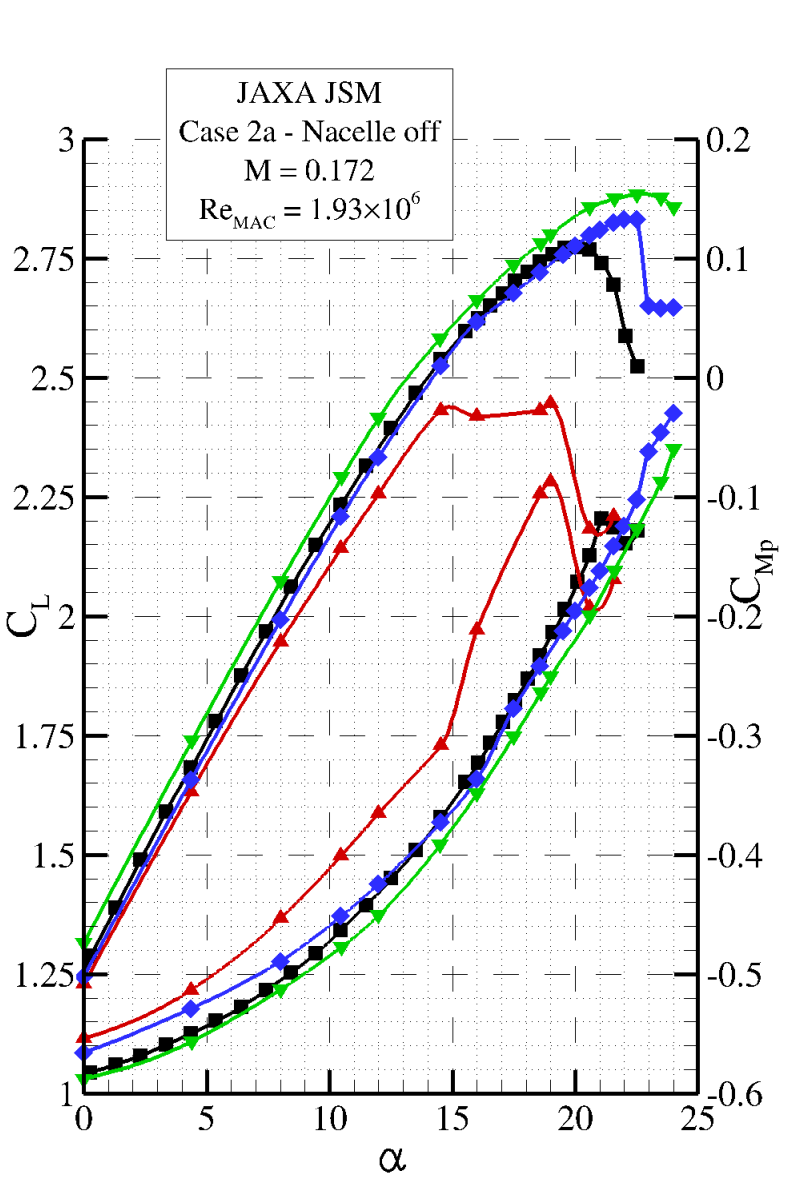
- Fully-turbulent flow assumption not valid at low WT Reynolds number
- Improvements to initial results come from two factors:
  - Curvature correction in k-ω model
  - Imposed laminar-turbulent transition
- Transition should be predicted rather than imposed
- Nacelle installation effects properly predicted
- Main flow features can be captured with a medium grid but volumic refinement/adaptation could help
- Free-stream CFD can predict half-model WT data, but discrepencies in absolute levels of drag and pitching moment remain that can be related to half-model effect

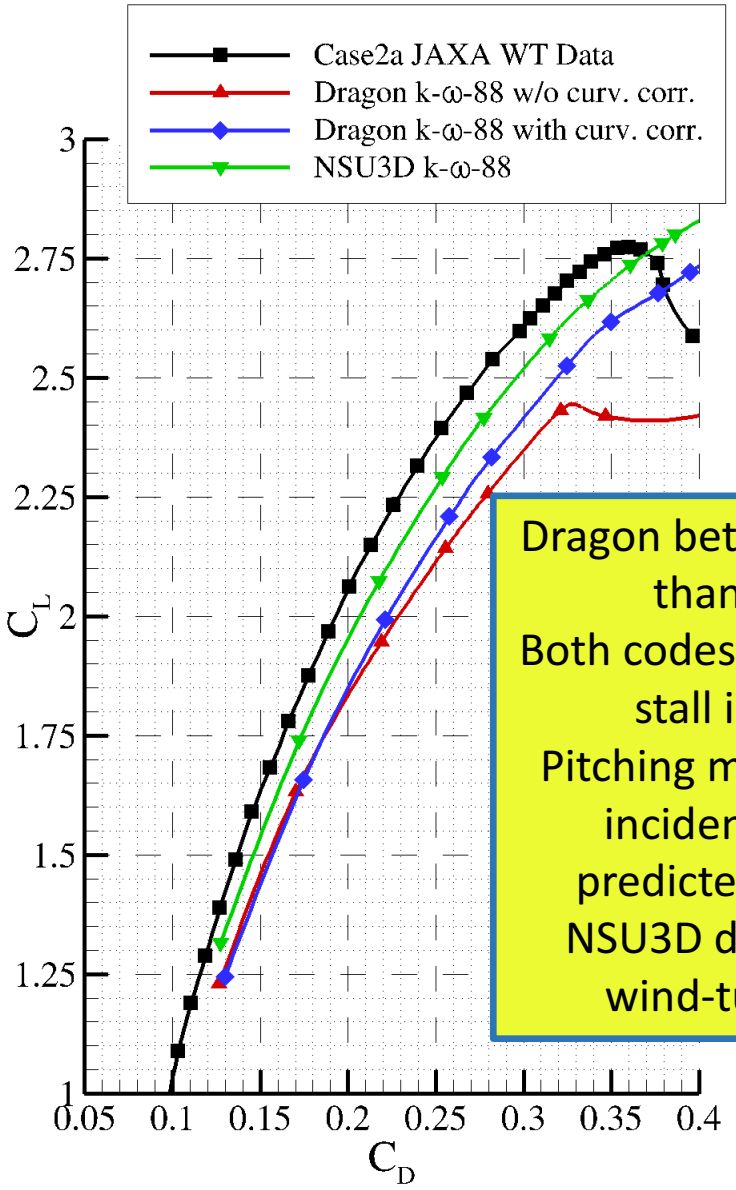
Thanks

Questions?

Back-up material

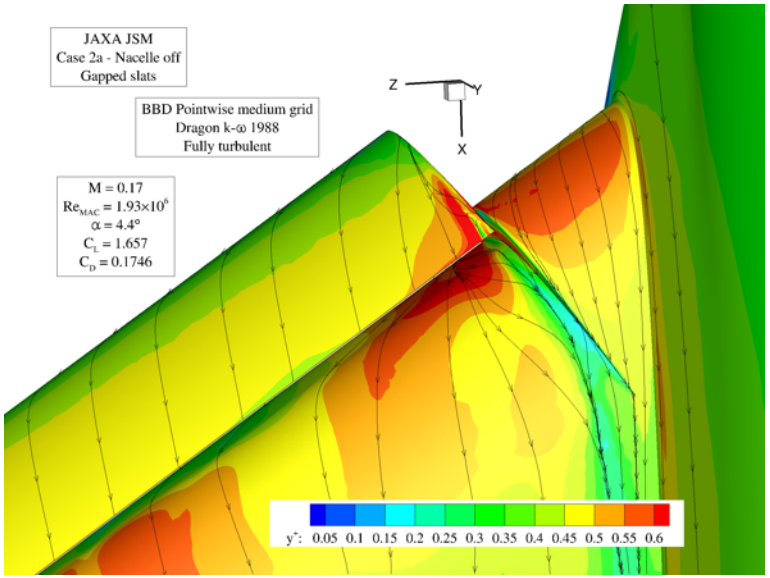
Comparison with NSU3D: forces & moments

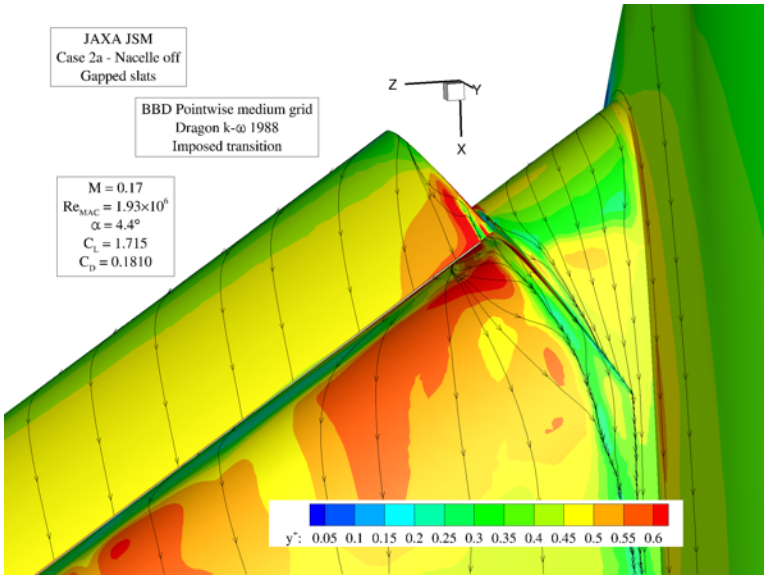


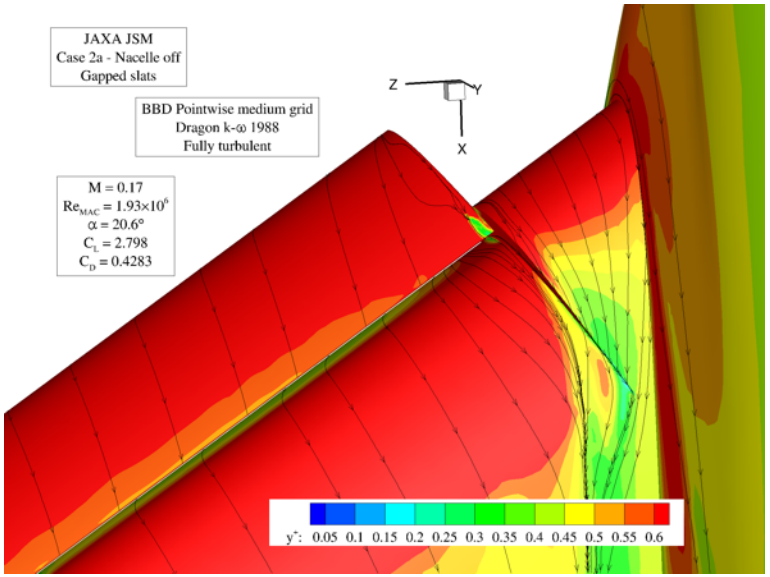


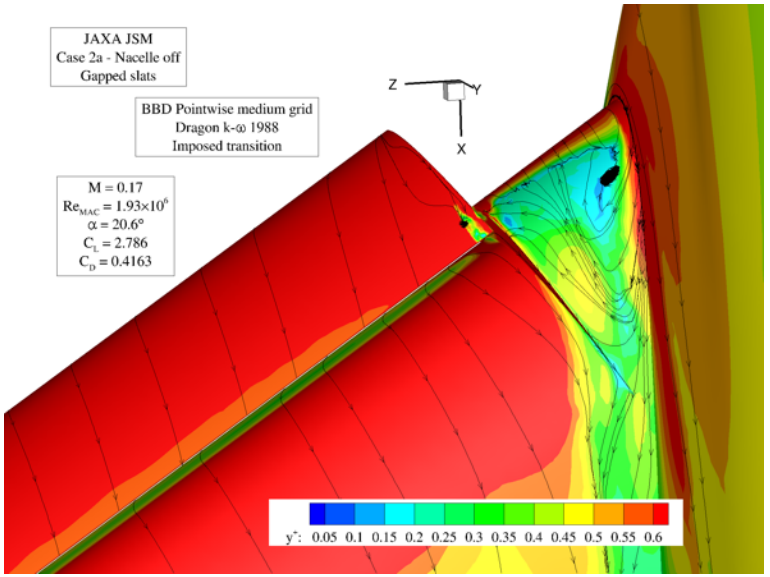
Dragon better predicts lift than NSU3D
Both codes predict similar stall incidence
Pitching moment at low incidences better predicted by NSU3D
NSU3D drag closer to wind-tunnel data

JAXA JSM results
Transition influence: surface flow pattern on IB fixed LE

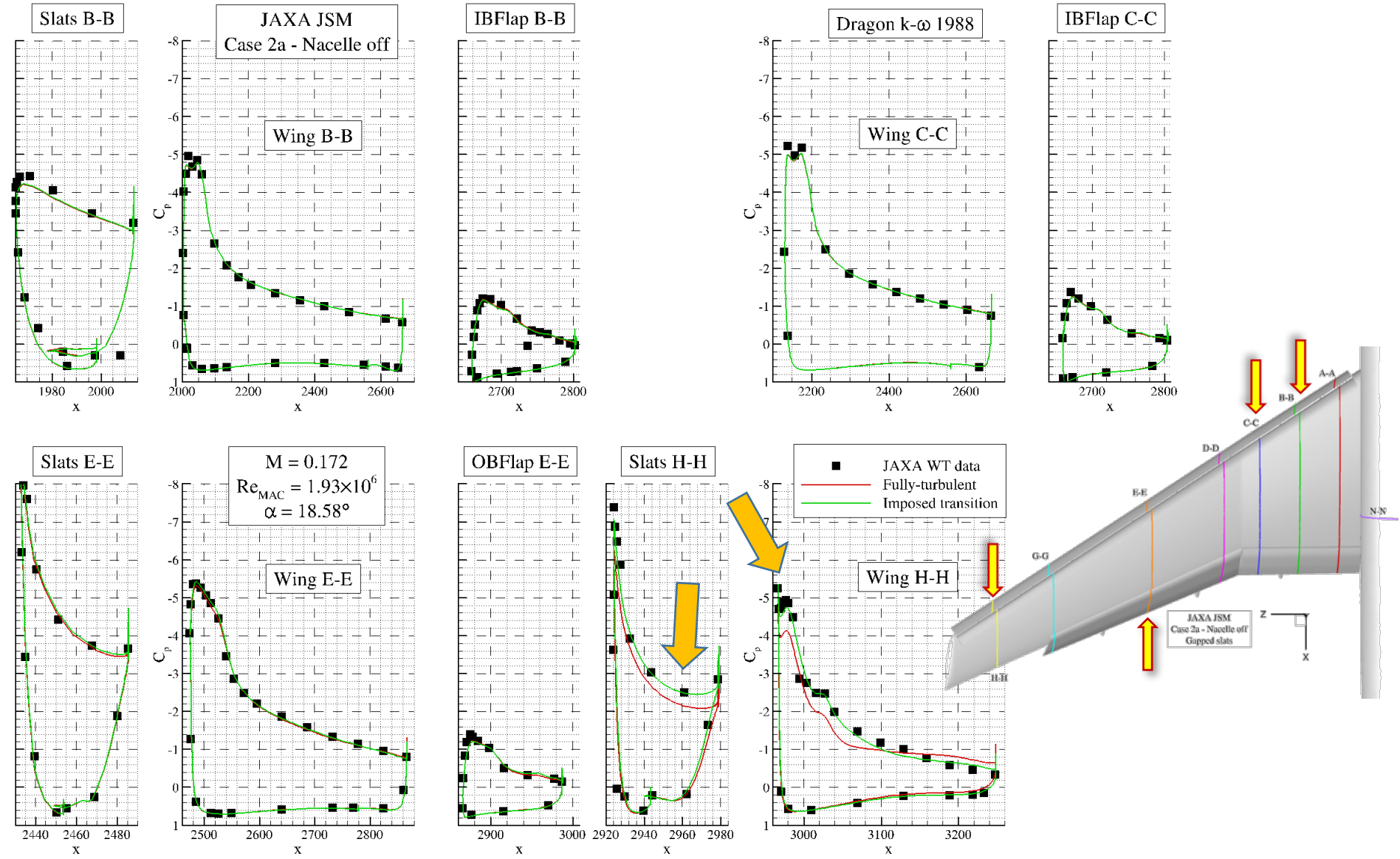




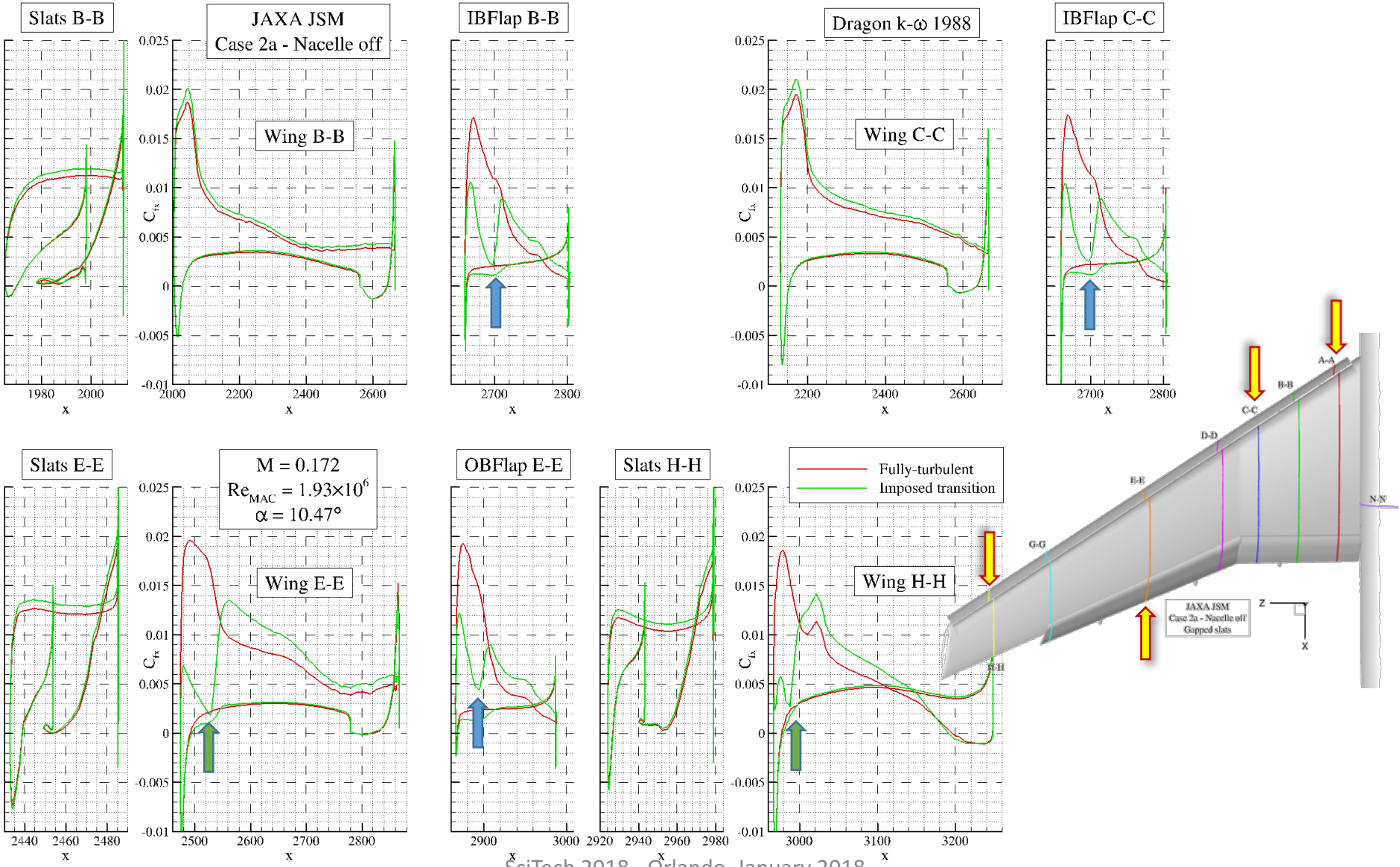




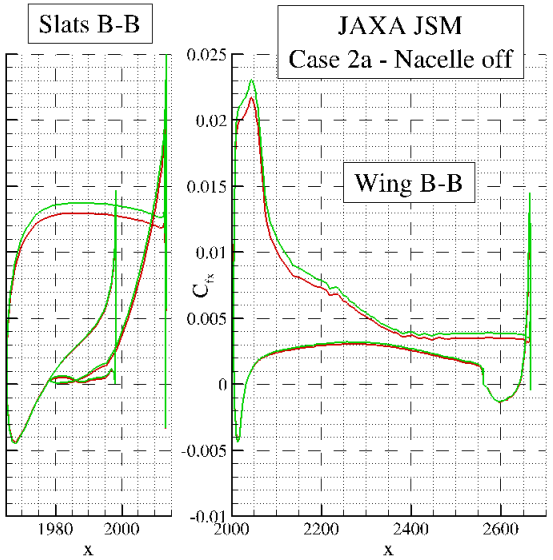
JAXA JSM results
Transition influence: pressure distributions

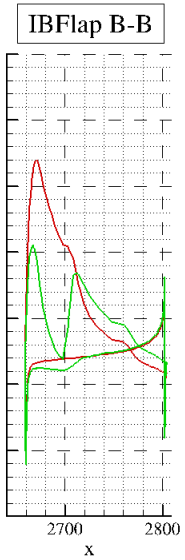


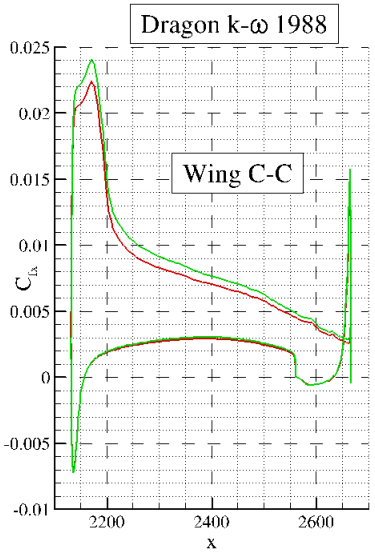
JAXA JSM results
Transition influence: skin friction (mid α)

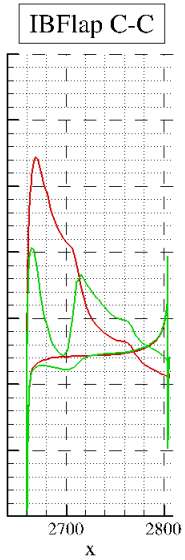


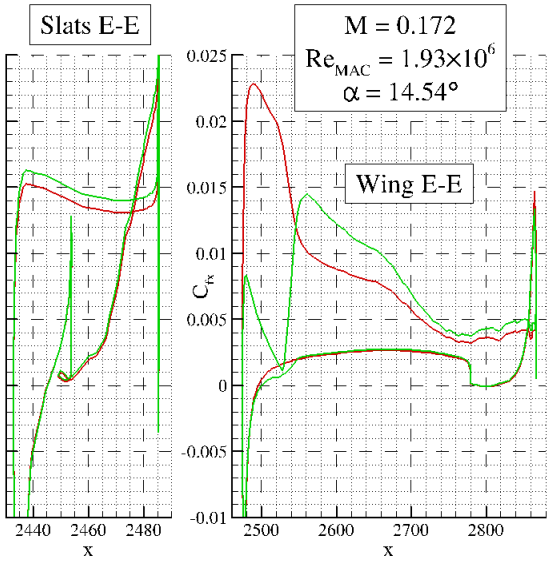
JAXA JSM results
Transition influence: skin friction

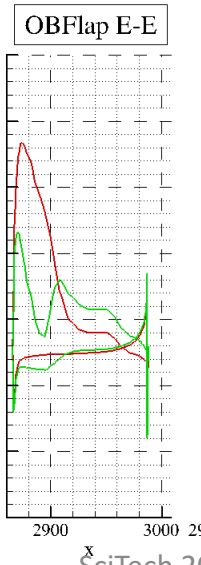


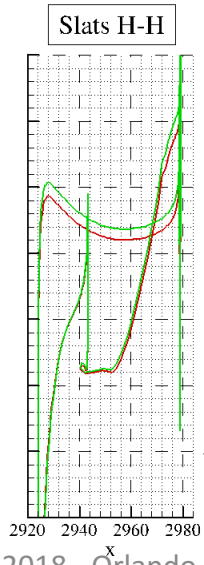


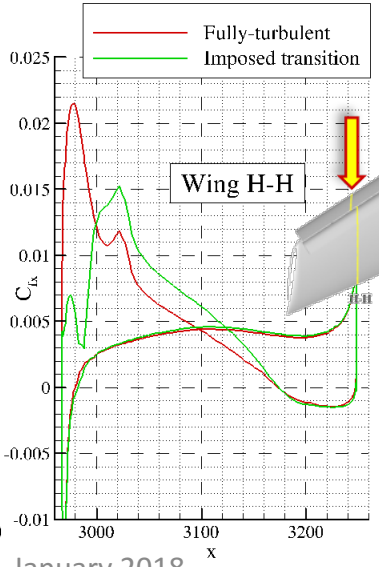


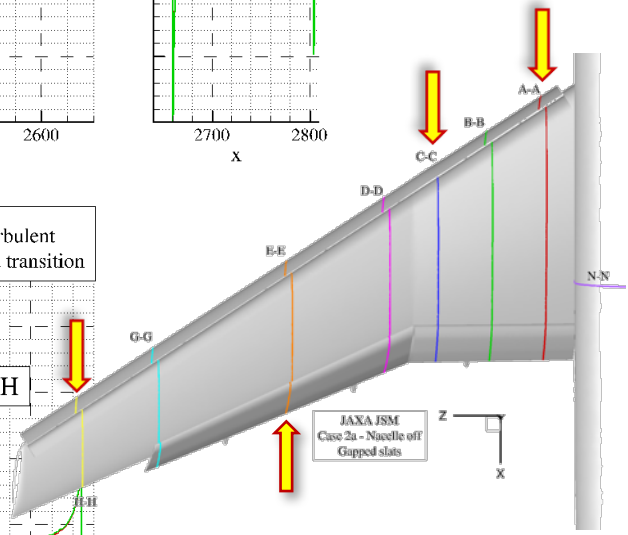




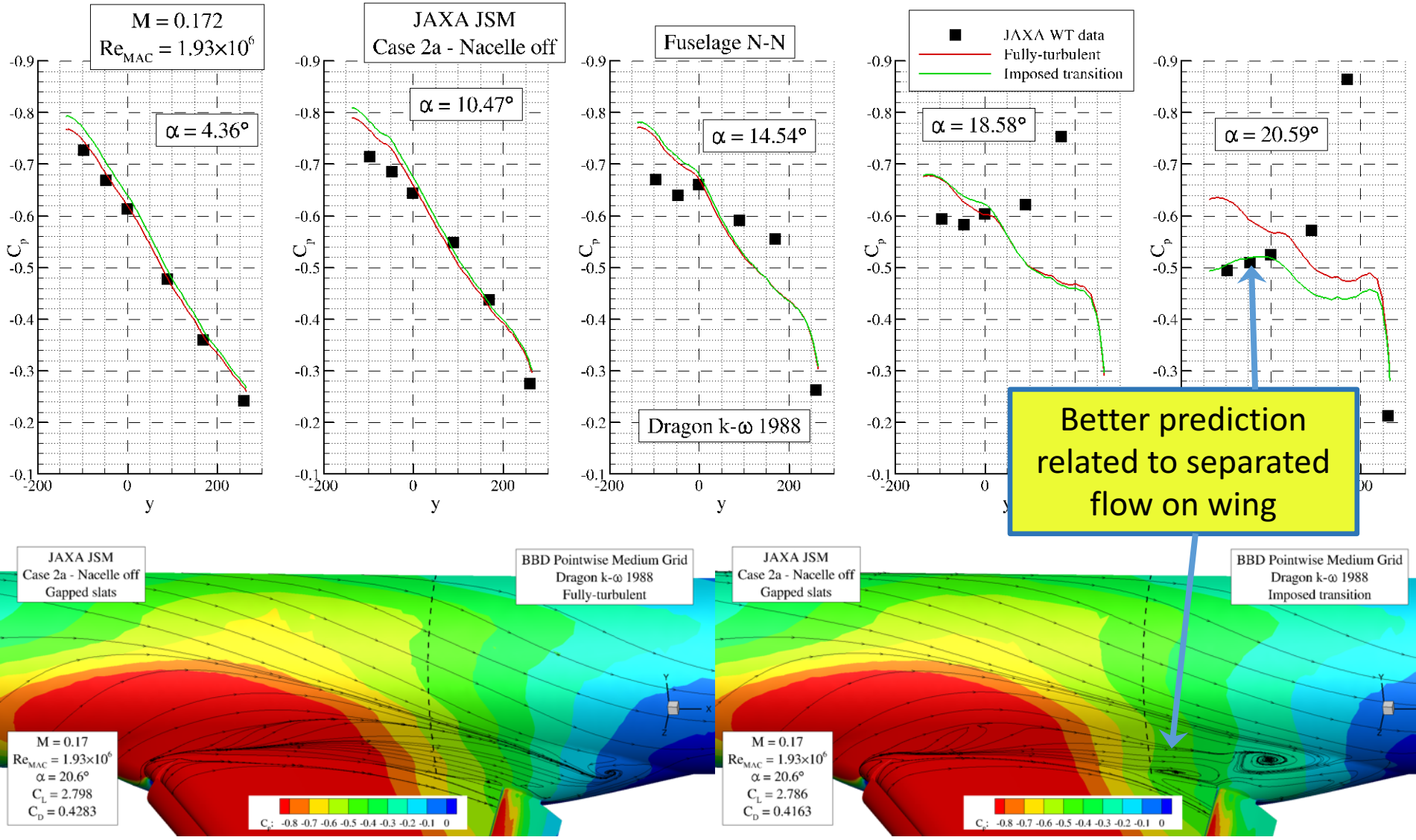




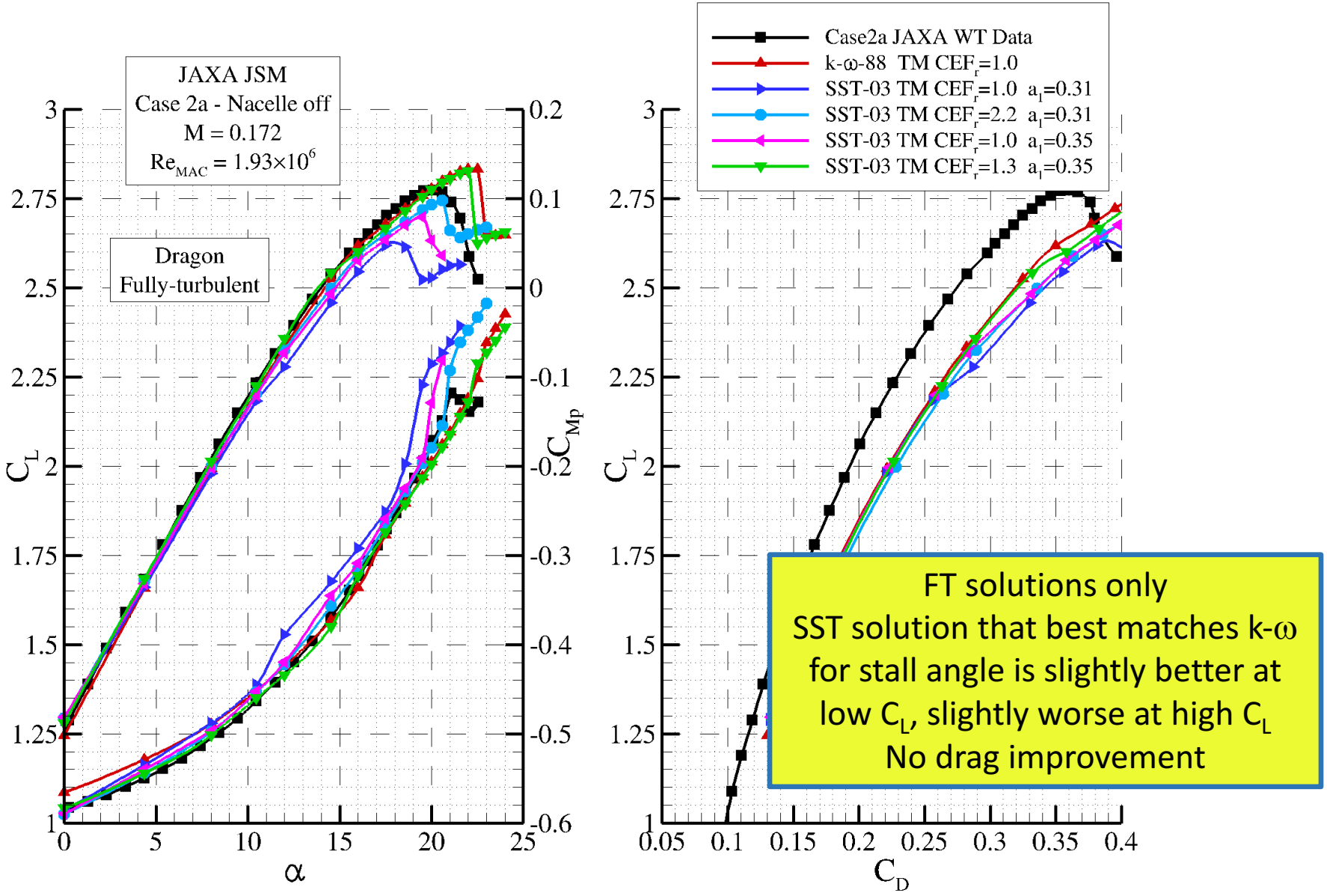




Transition influence: pressure distribution on fuselage

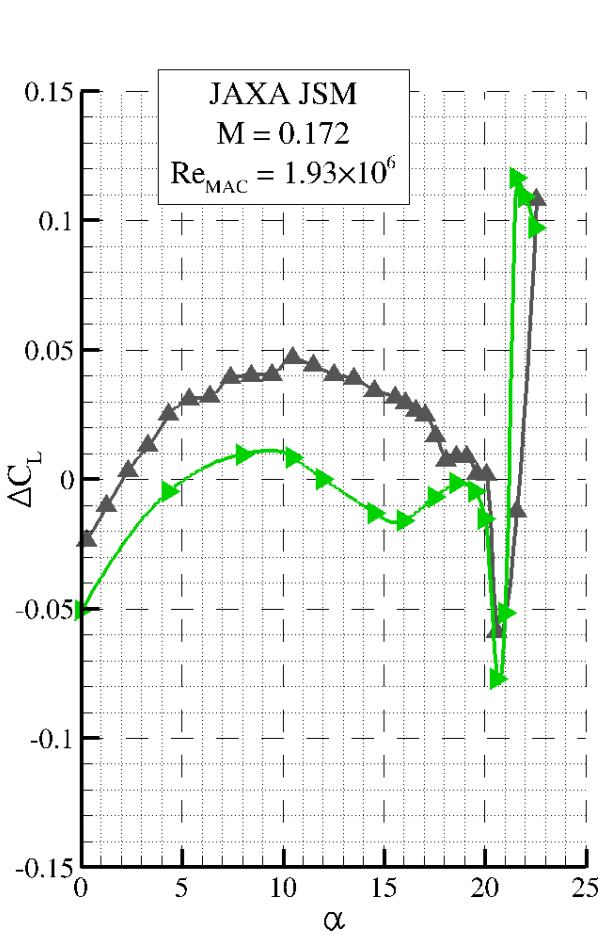


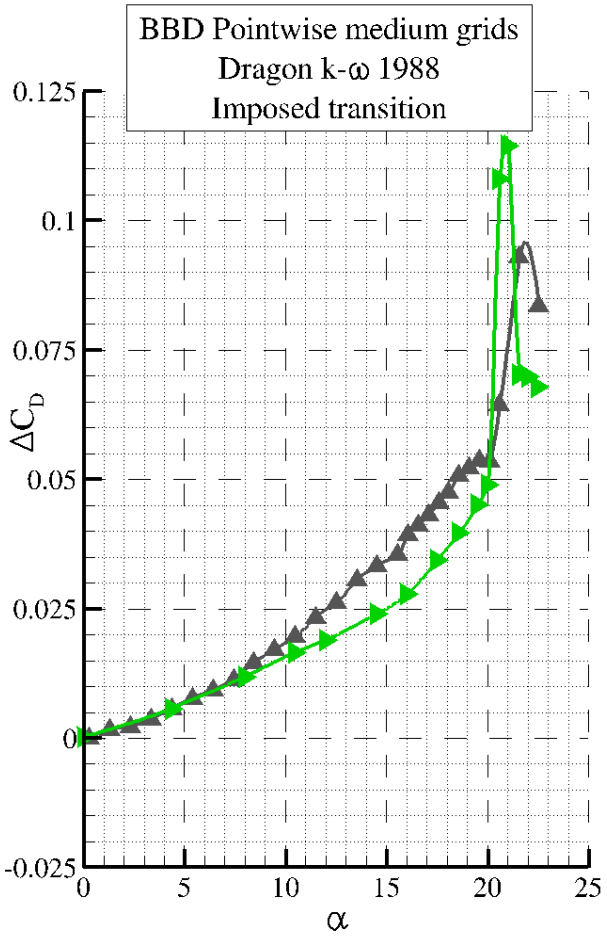
Turbulence model influence: forces & moment

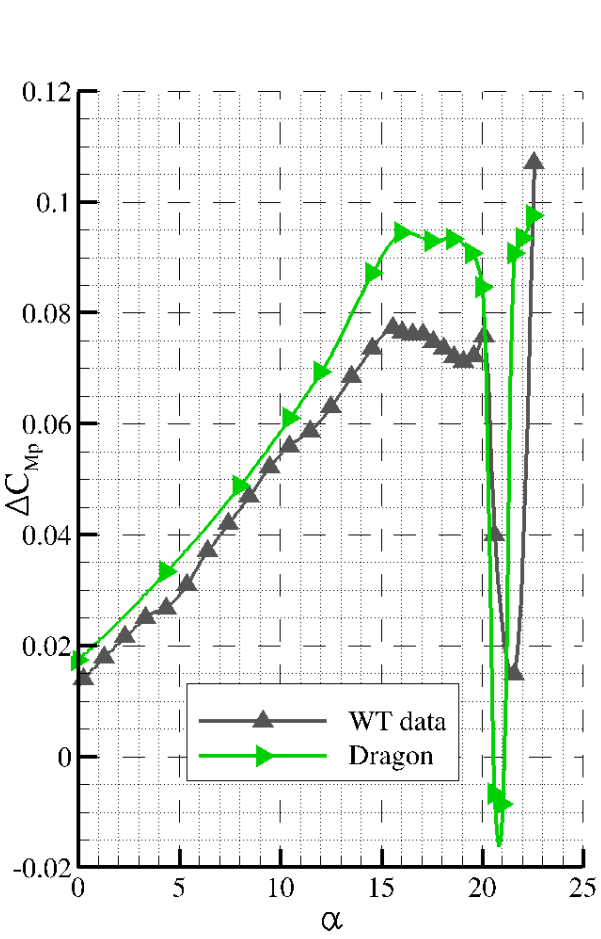


FT solutions only
SST solution that best matches k-ω for stall angle is slightly better at low C_L, slightly worse at high C_L
No drag improvement

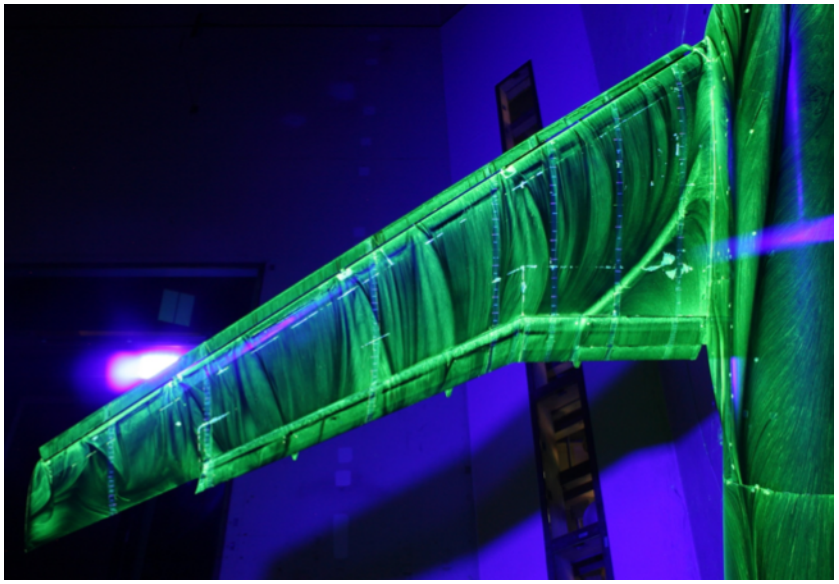
Nacelle installation: forces & moment variations

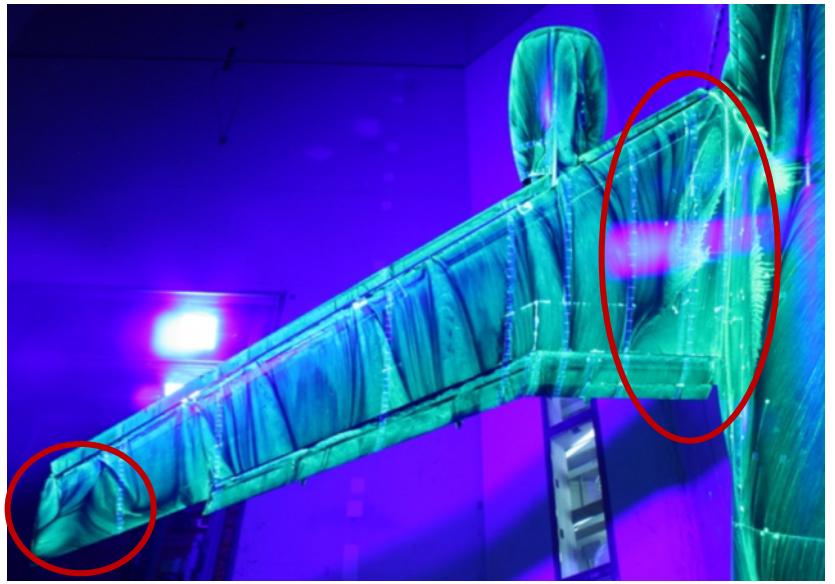


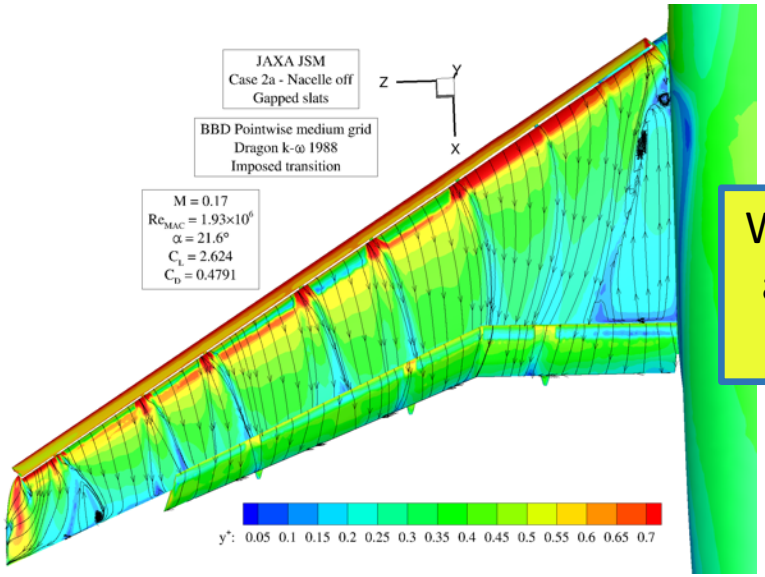




JAXA JSM results
Nacelle installation: surface flow pattern

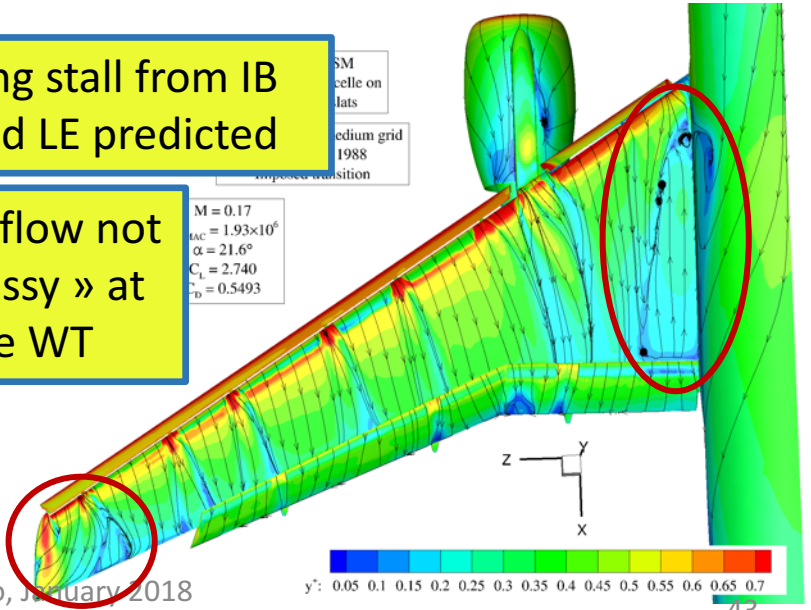




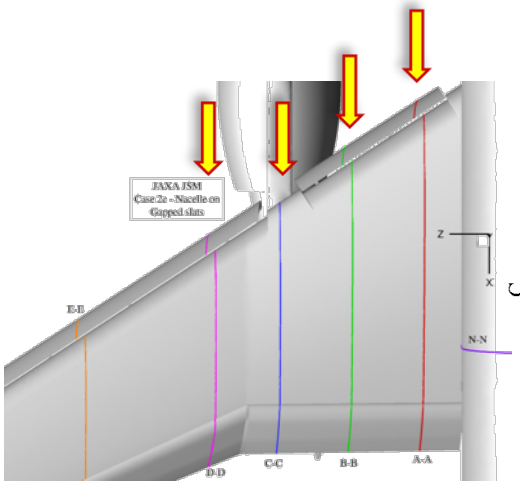


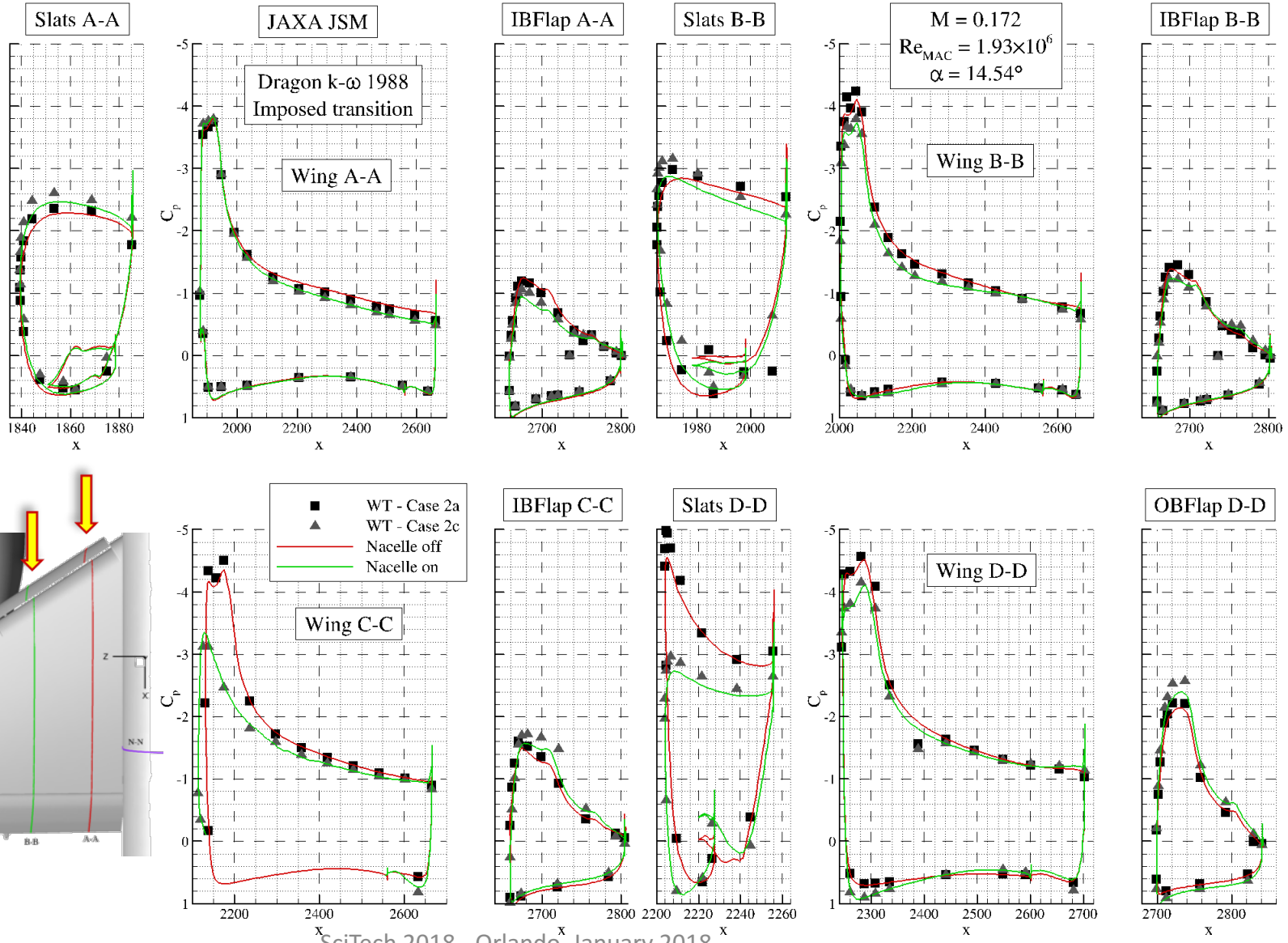
Wing stall from IB fixed LE predicted

Wingtip flow not as « messy » at in the WT



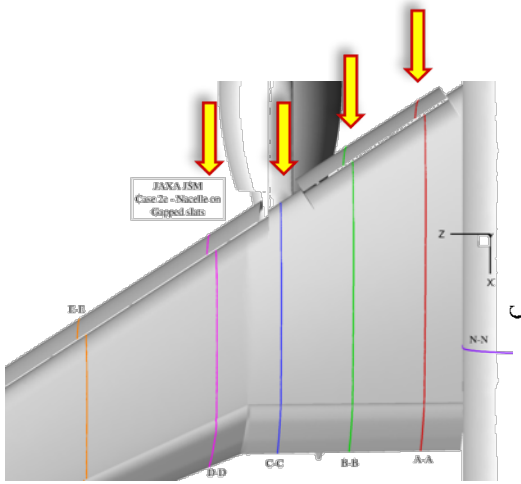
JAXA JSM results
Nacelle installation: pressure distributions

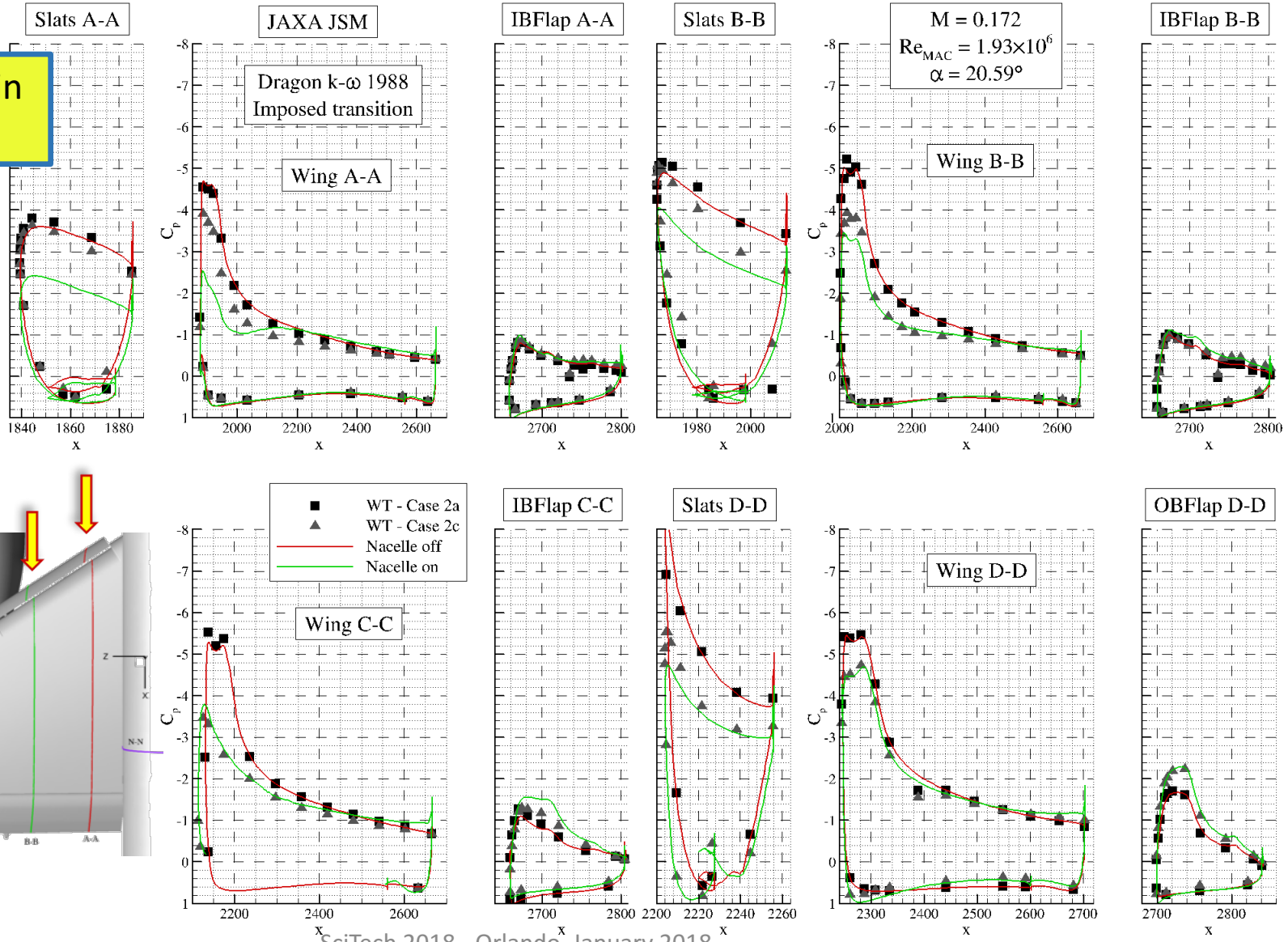




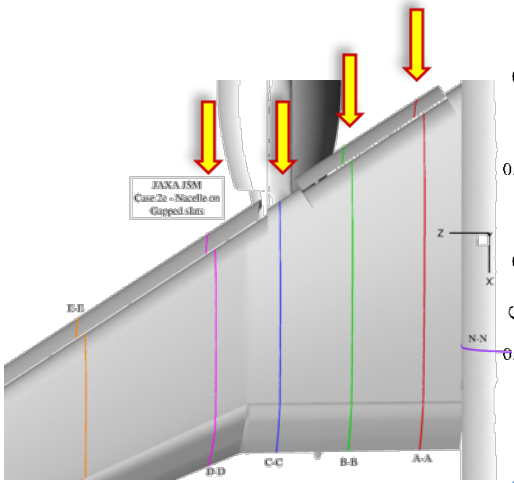
JAXA JSM results
Nacelle installation: pressure distributions

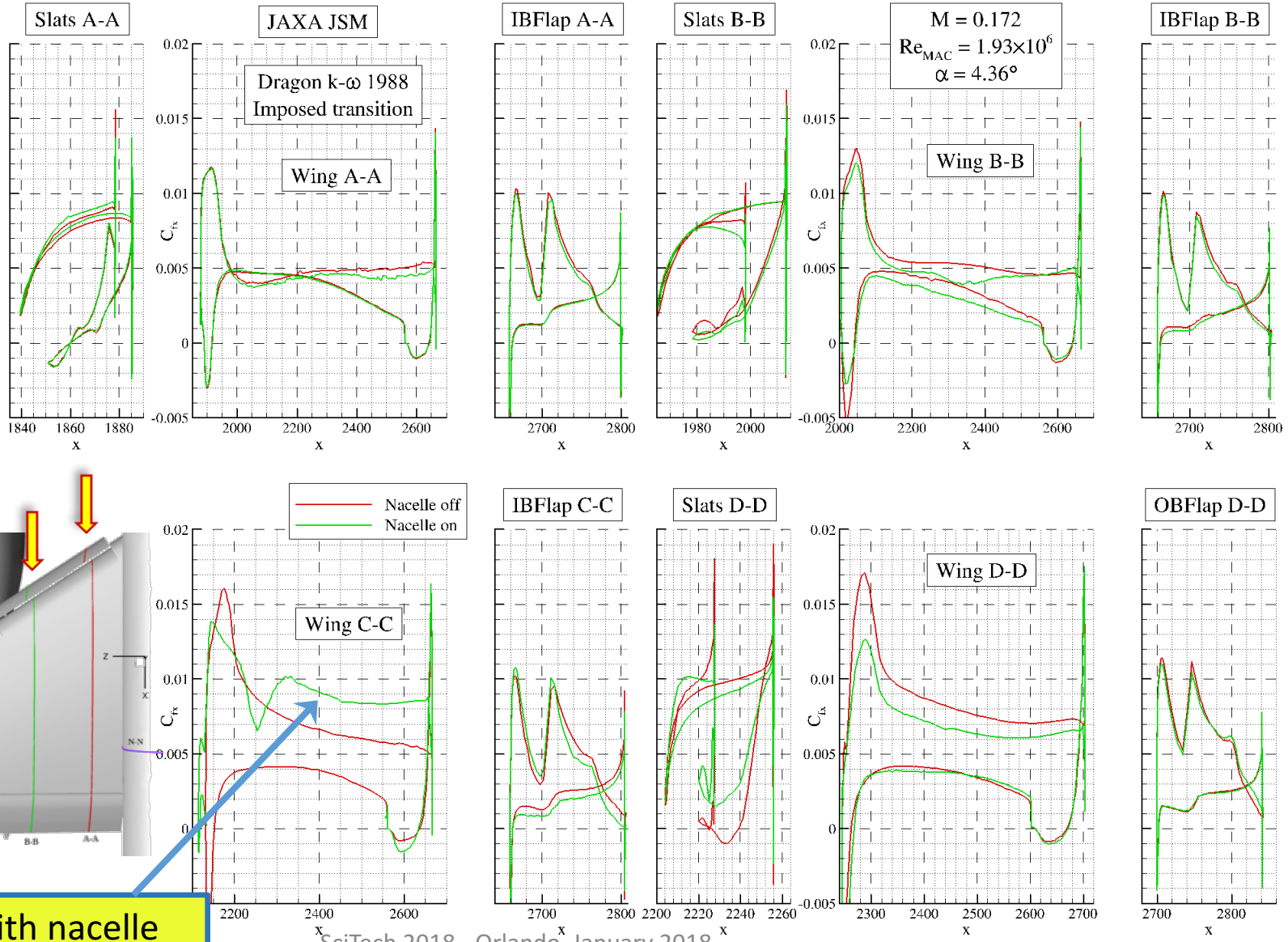
IB stall is again too abrupt





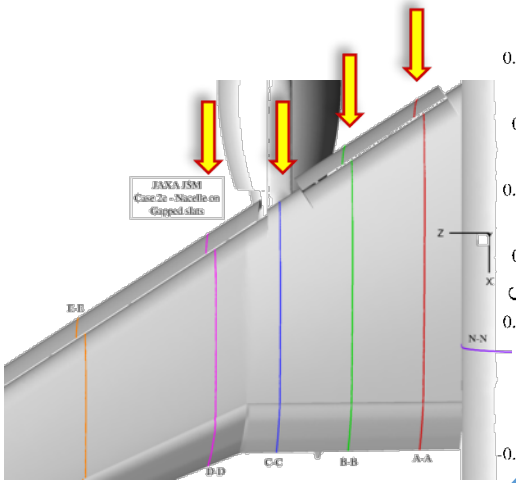
JAXA JSM results
Nacelle installation: skin friction

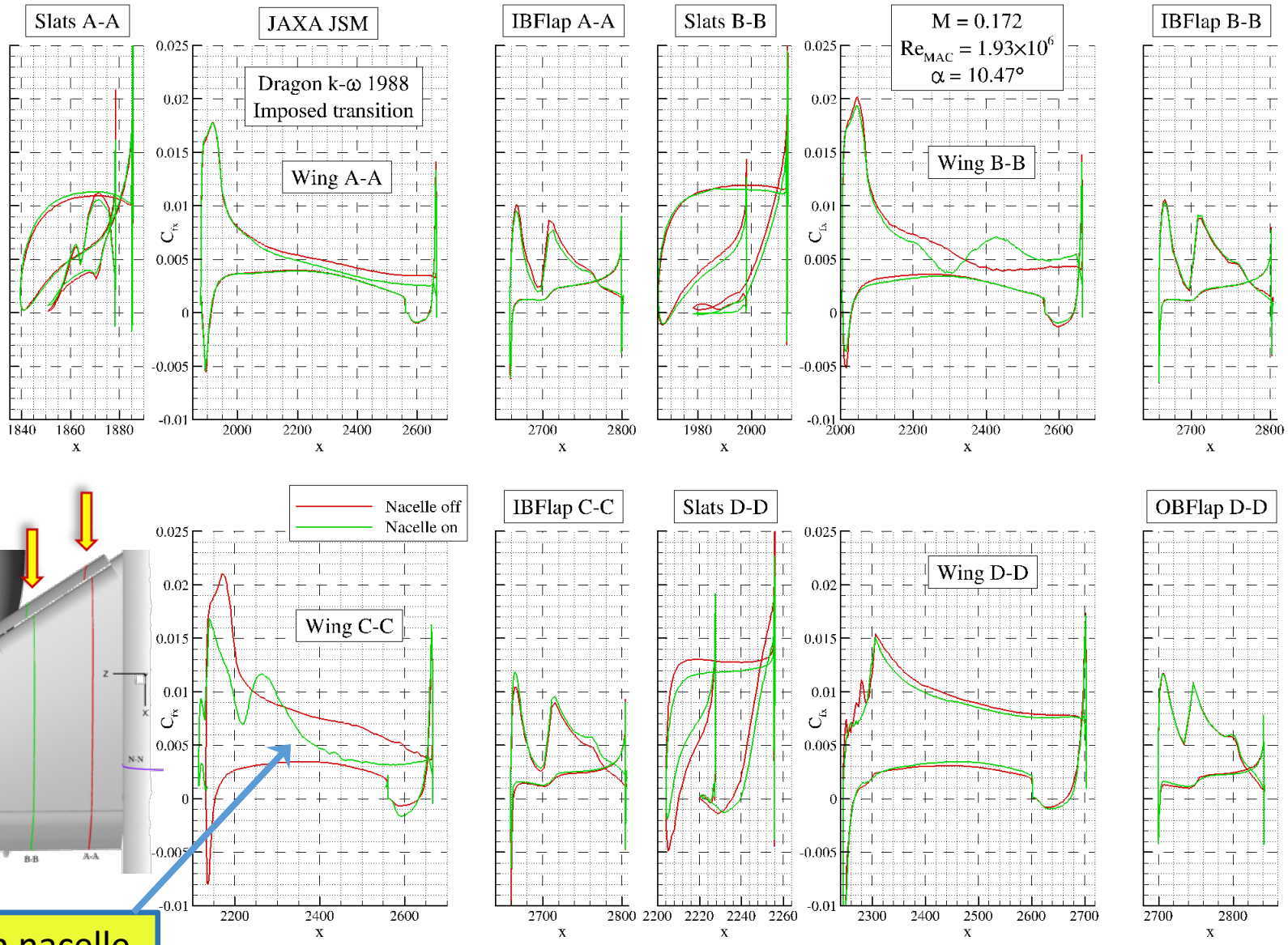




Higher C_f with nacelle

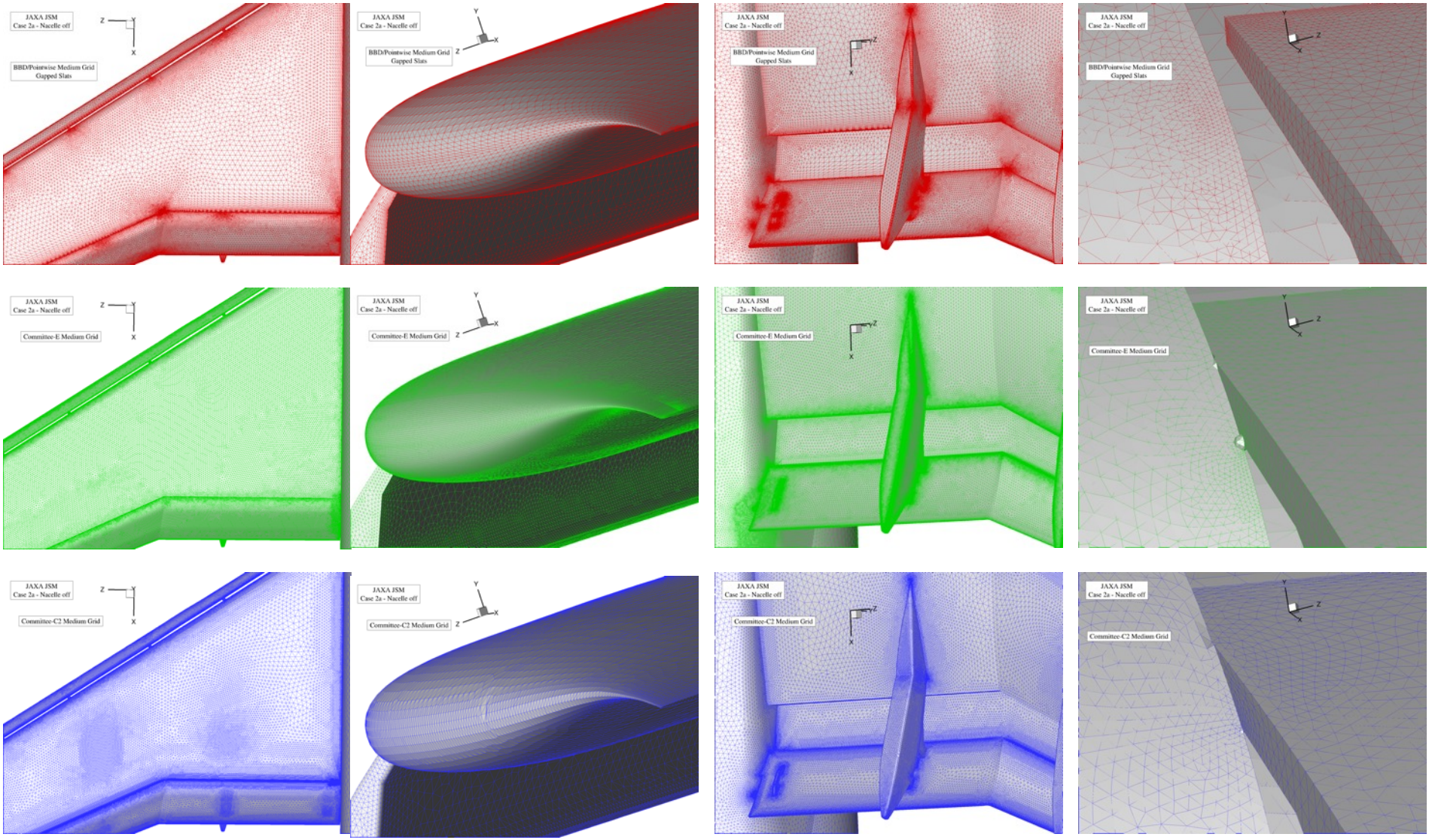
JAXA JSM results
Nacelle installation: skin friction



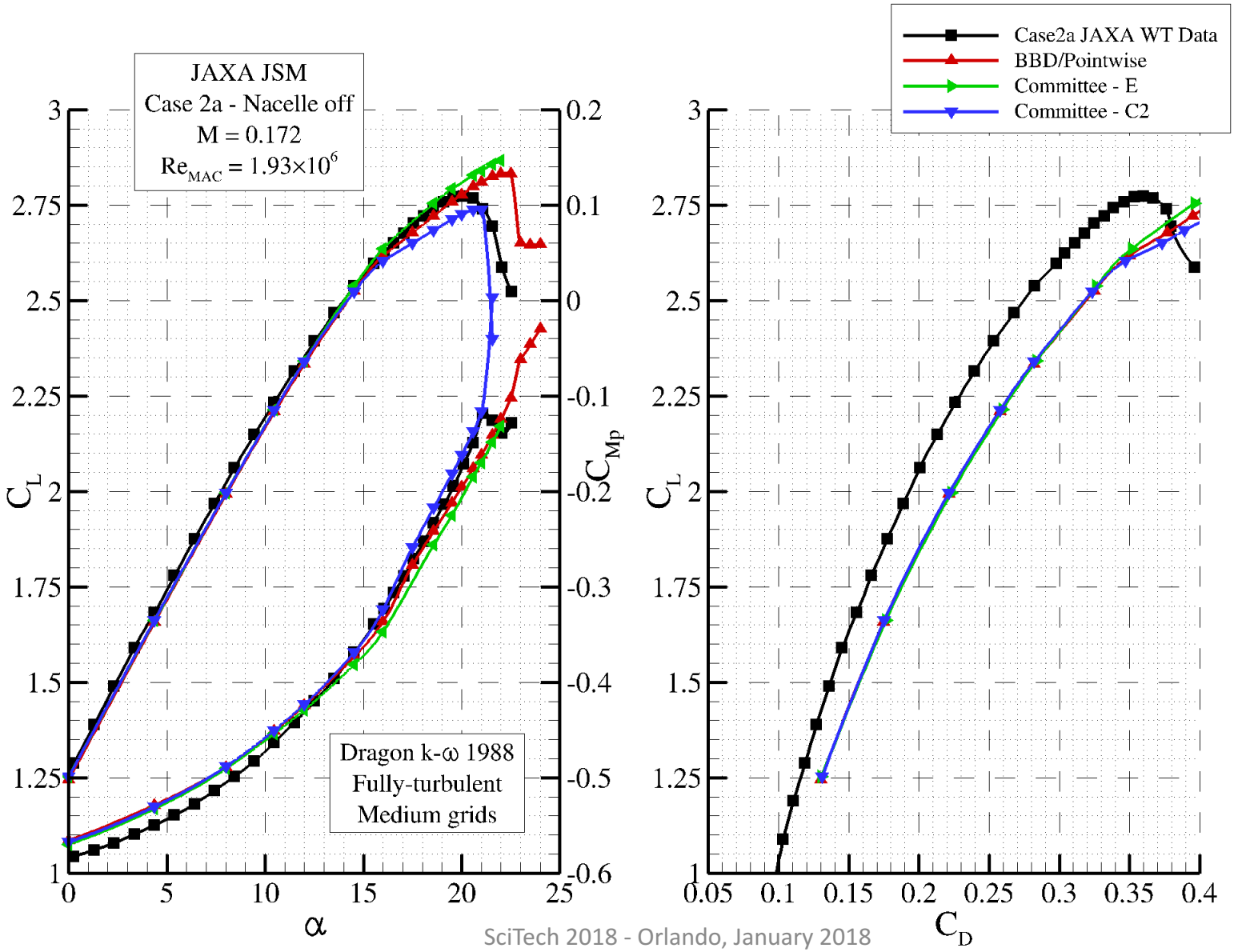


Lower C_f with nacelle

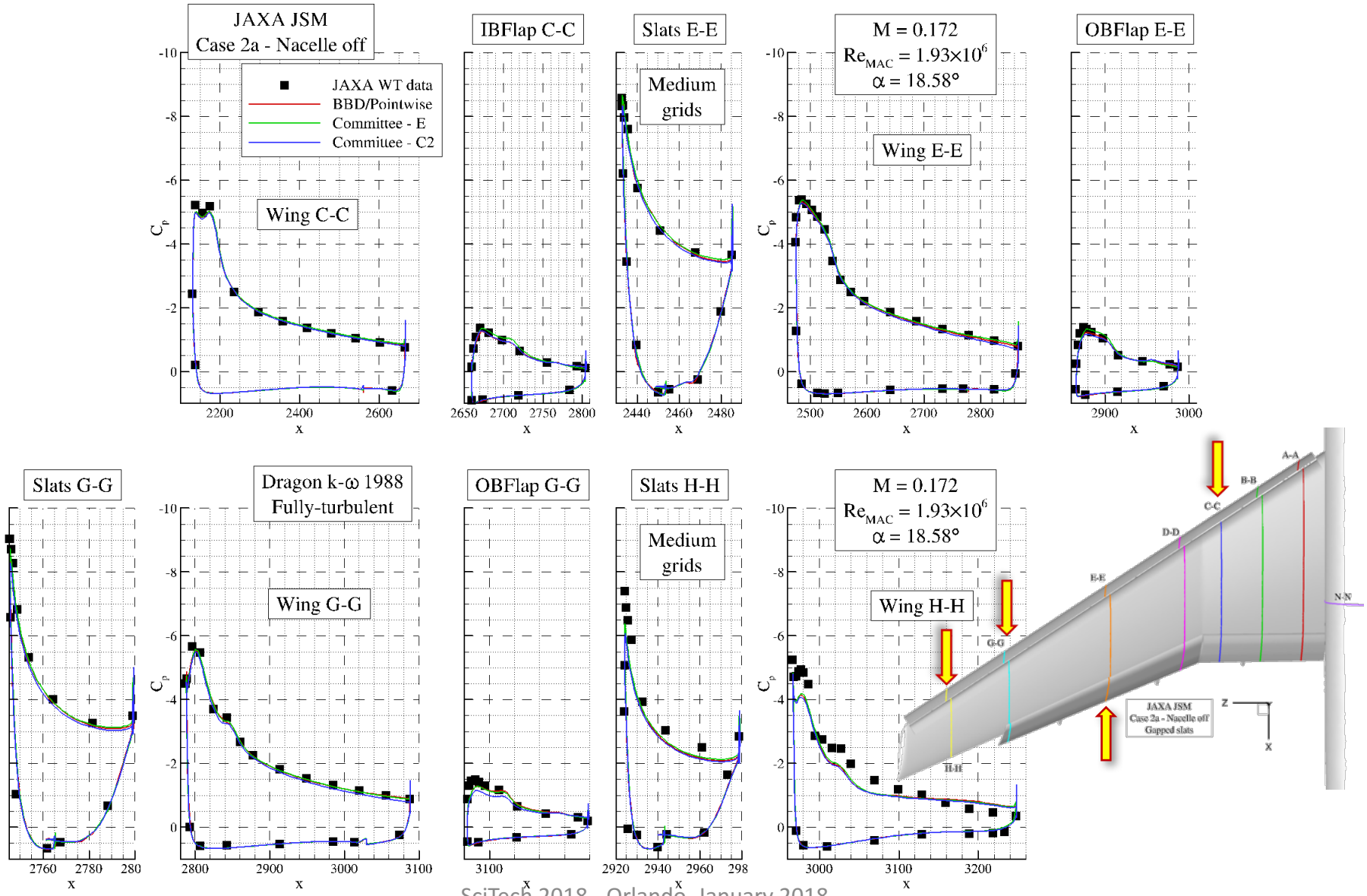
JAXA JSM results – Case 2a
Grid influence



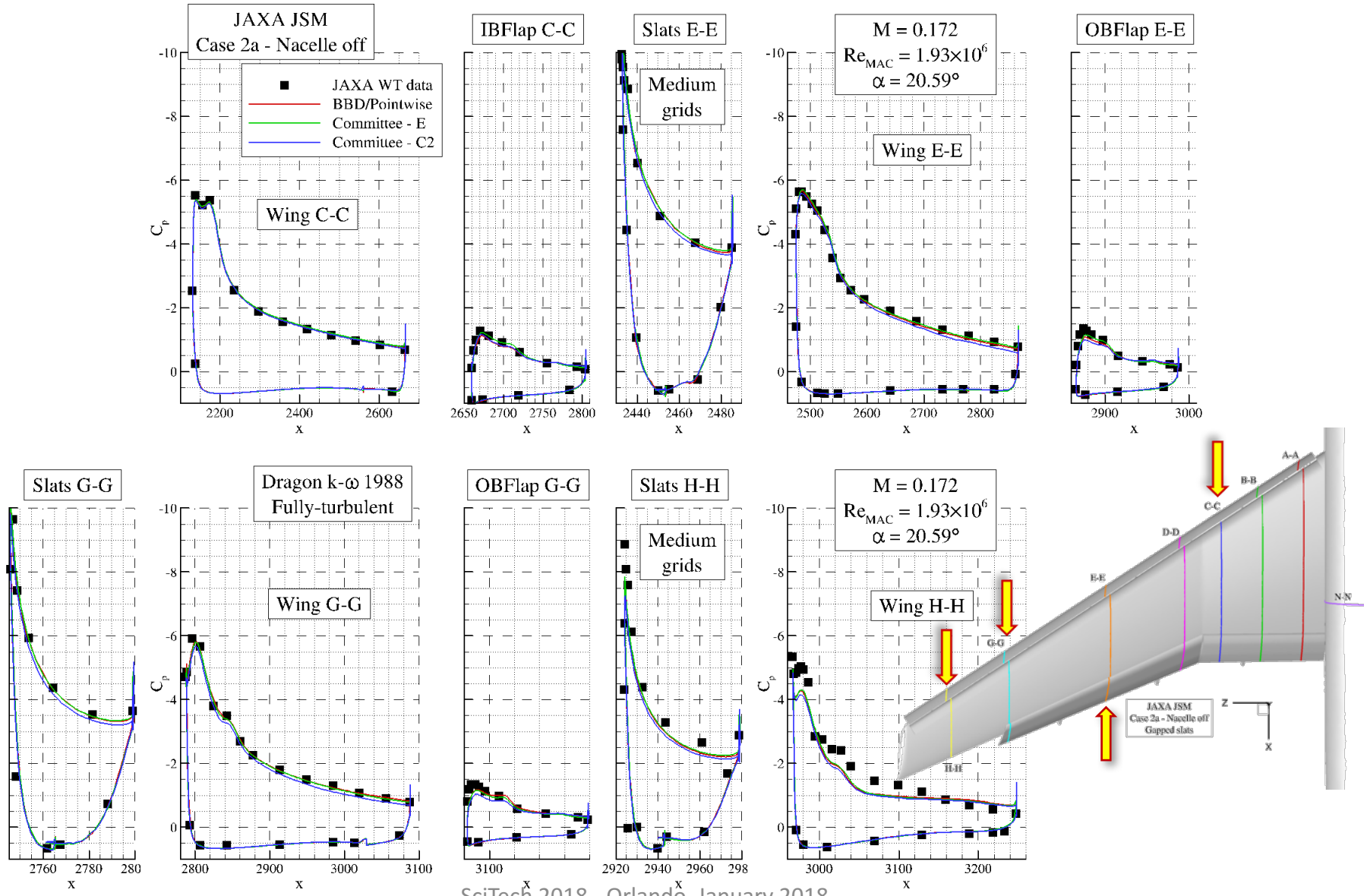
JAXA JSM results – Case 2a
Grid influence: forces and moments



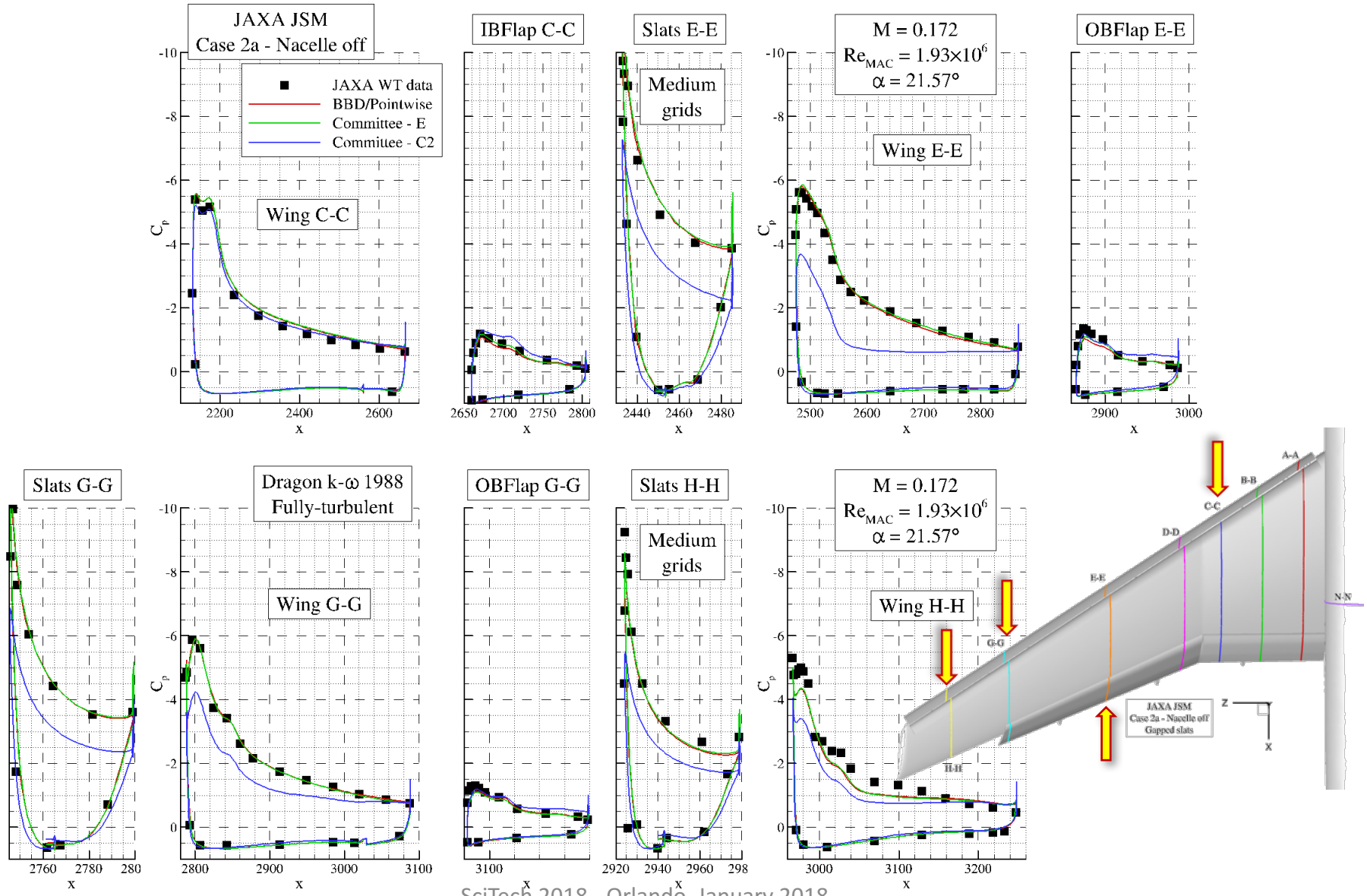
JAXA JSM results – Case 2a
Grid influence: pressure distributions



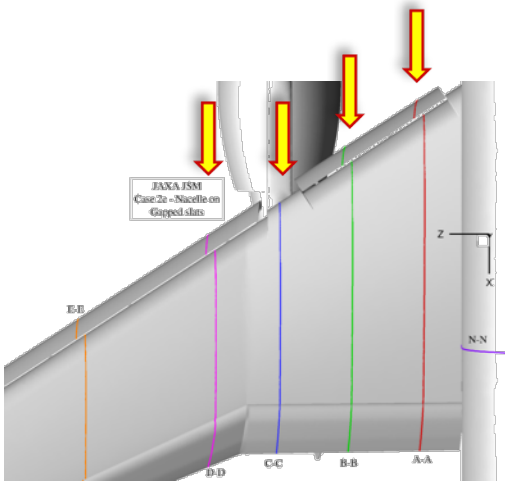
JAXA JSM results – Case 2a
Grid influence: pressure distributions

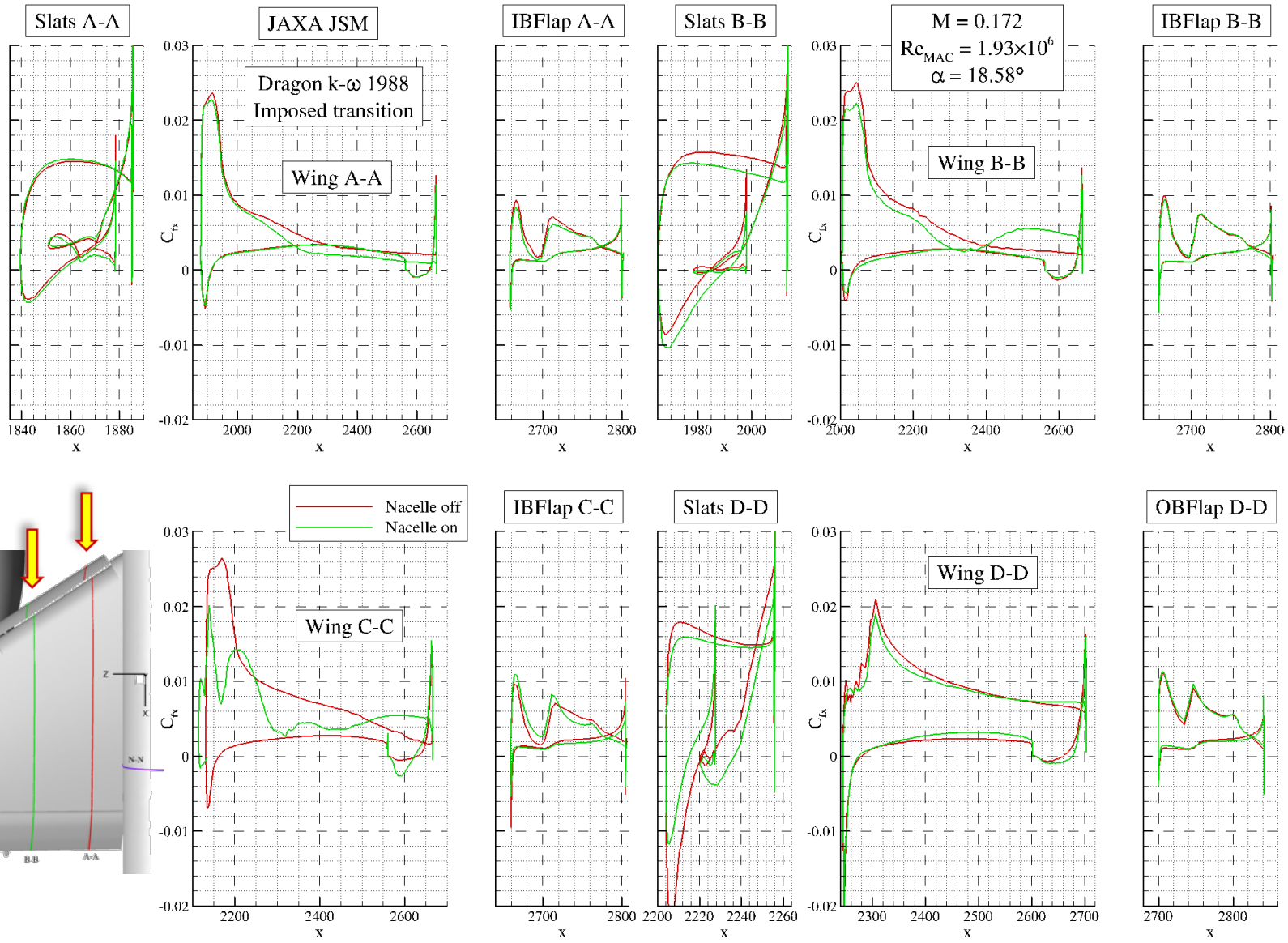


JAXA JSM results – Case 2a
Grid influence: pressure distributions

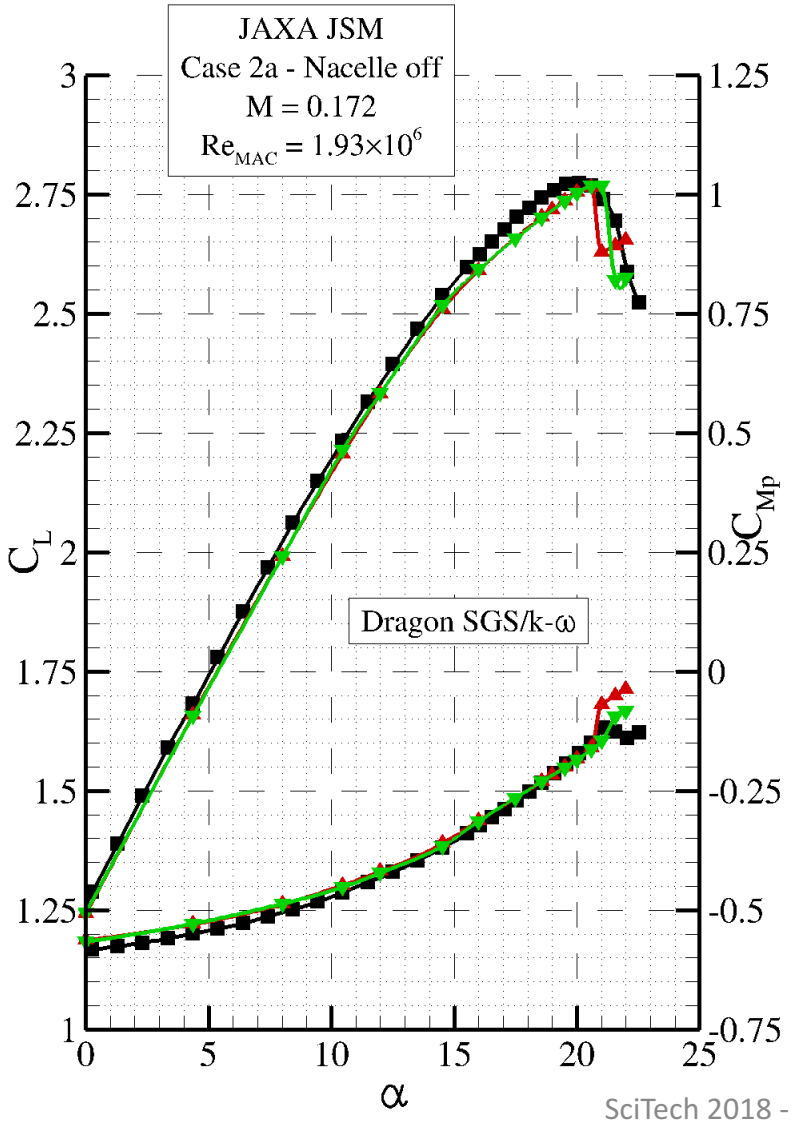


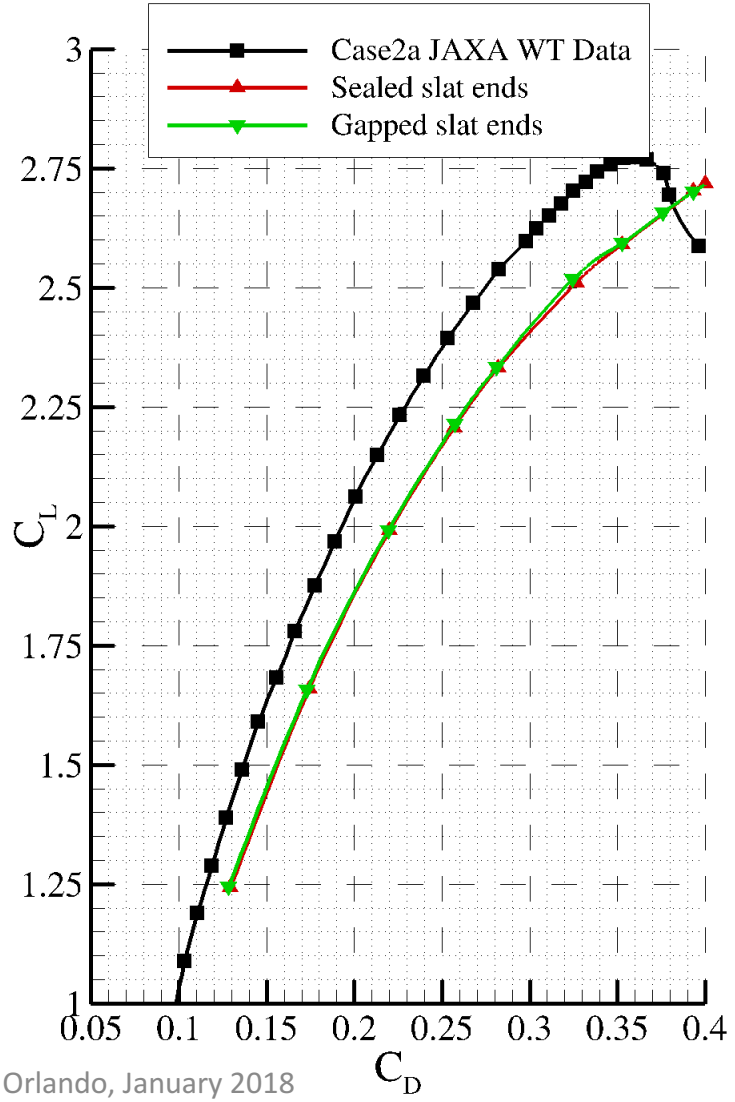
JAXA JSM results
Nacelle installation: skin friction



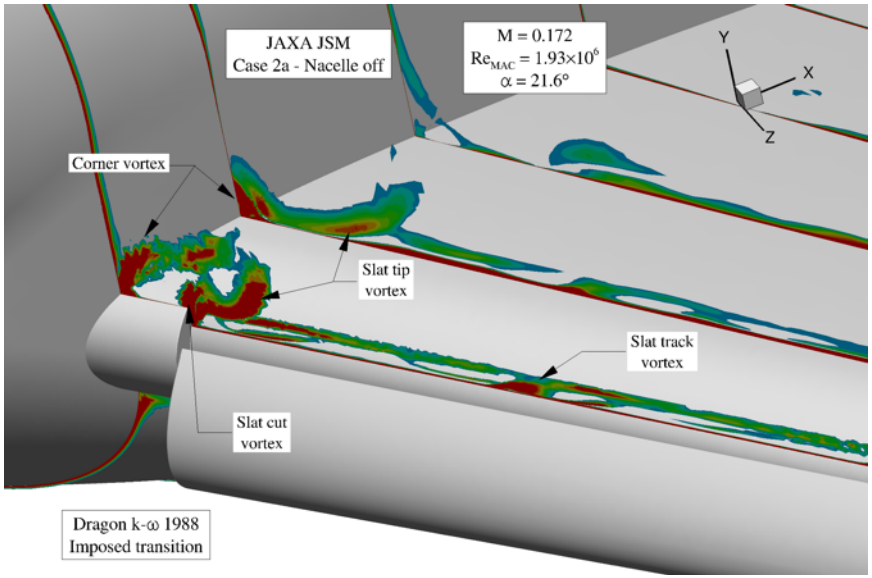


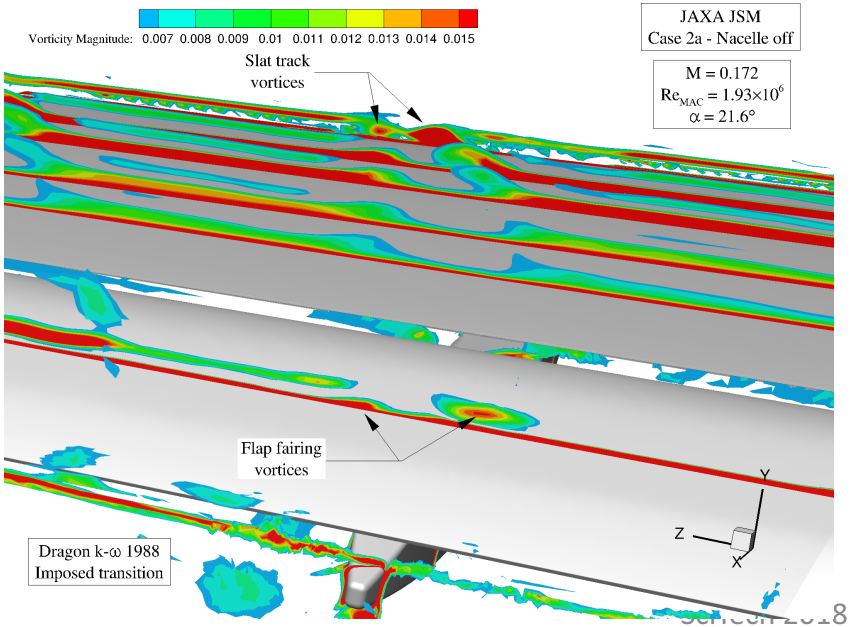
JAXA JSM results – Case 2a
Slat gaps influence: forces and moments

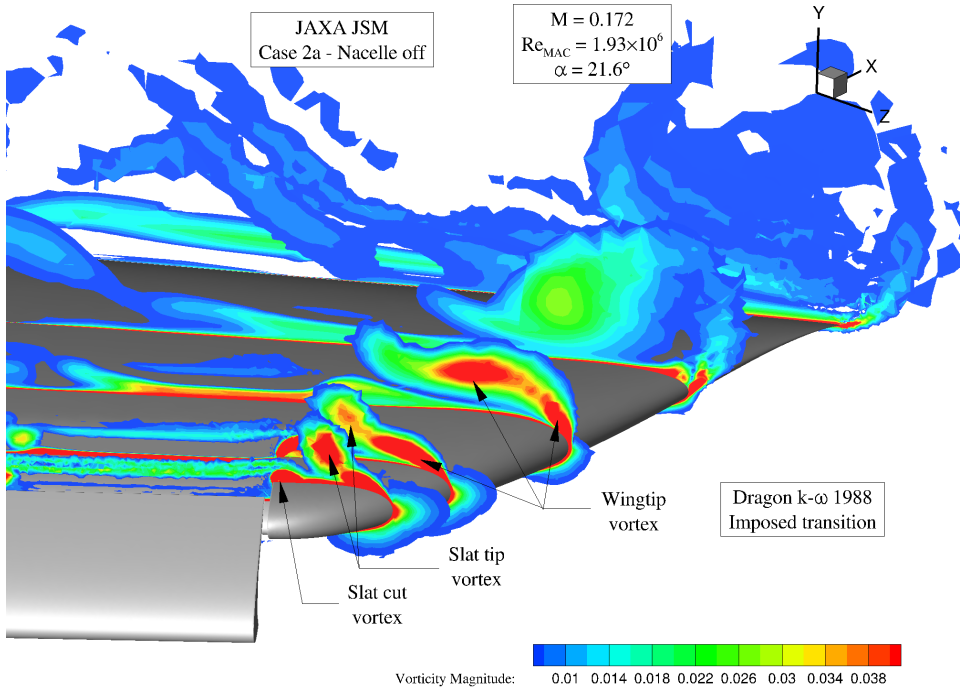




Nacelle-off configuration: volume plots (post-stall)

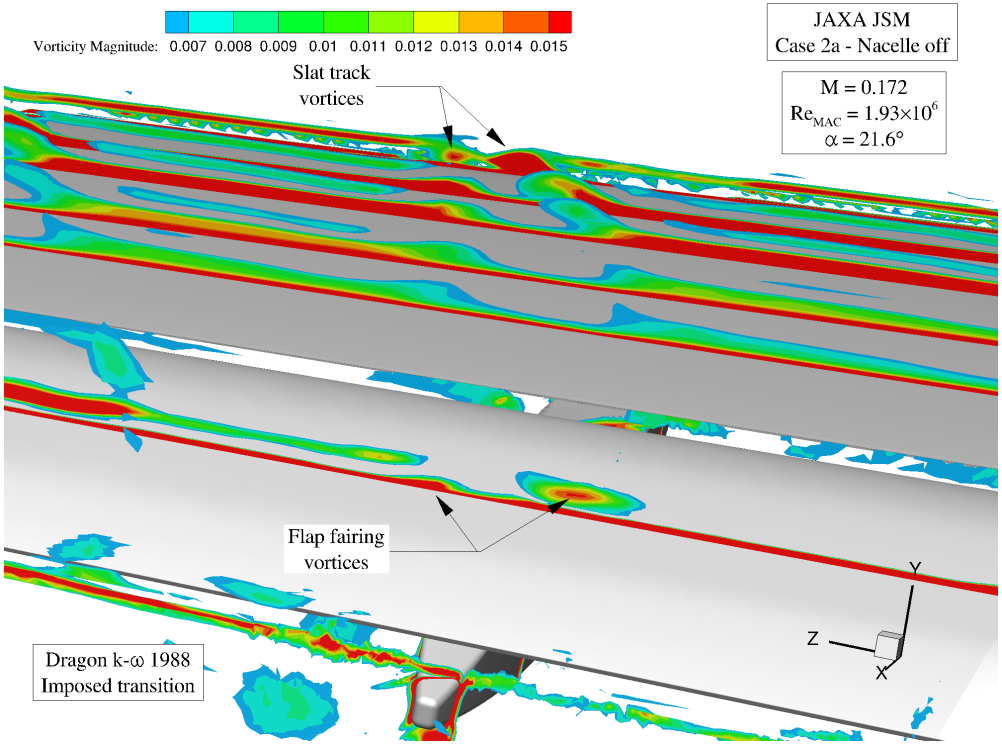


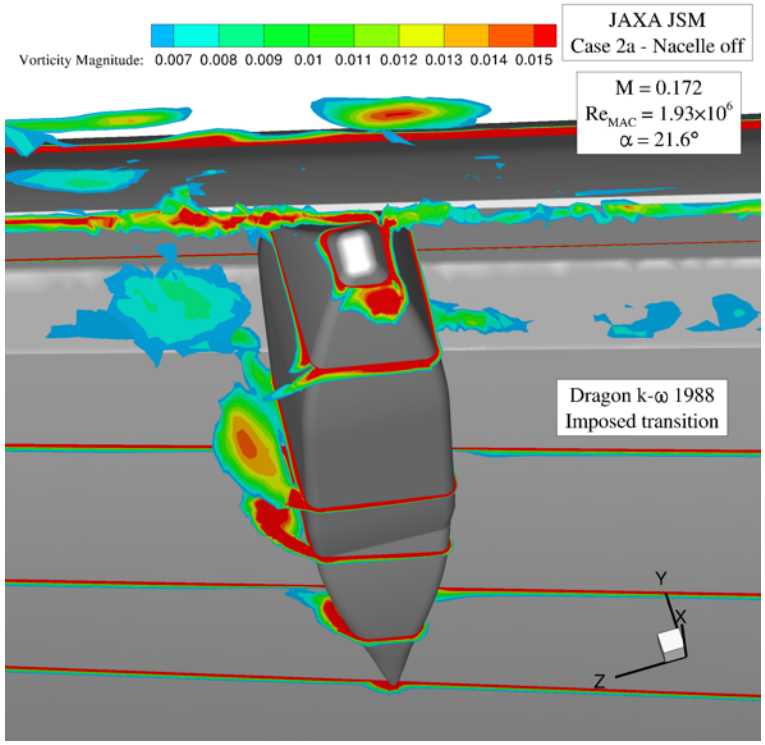




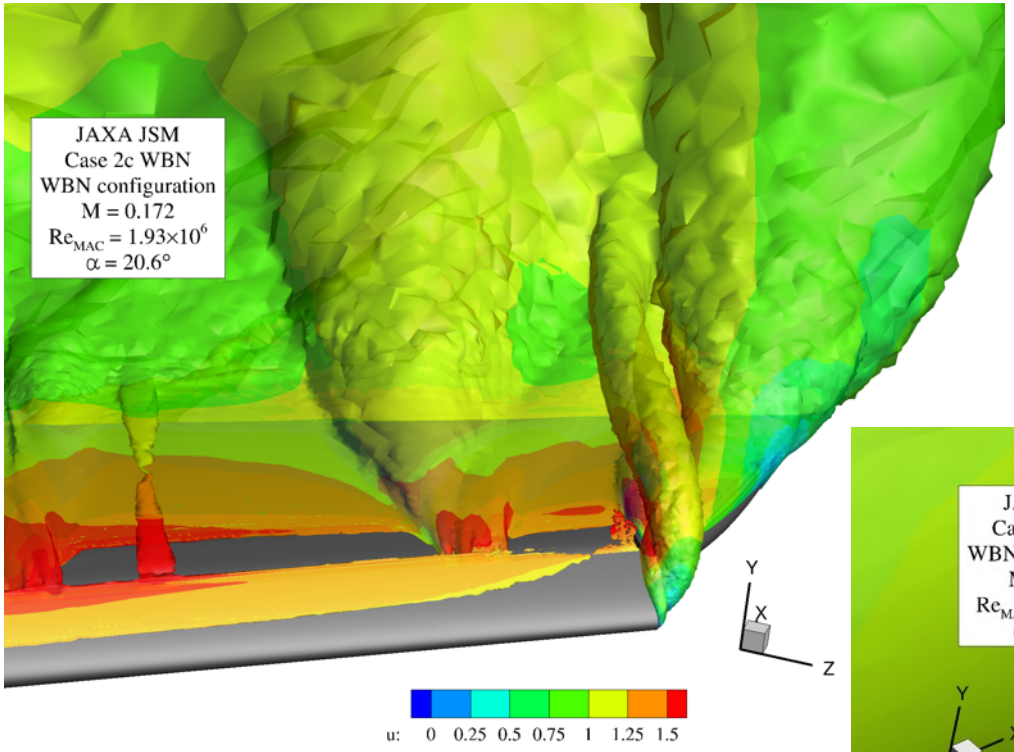
Main flow features are captured but likely dissipate too quickly
Volumic refinement/adaptation would be required

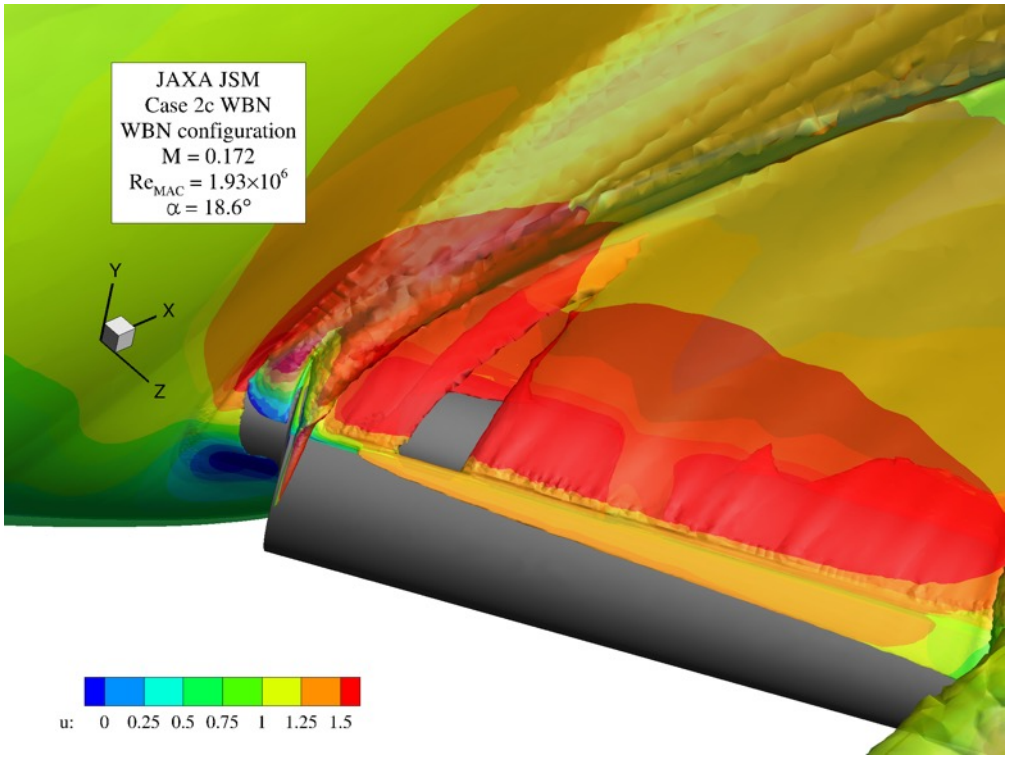
JAXA JSM results
Nacelle-off configuration: volume plots





Nacelle-on configuration: volume plots





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